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MASTERING
BIOLOGY

O. F. G. KILGOUR

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DEDICATION

To Irene Rachelle and Janet Katharine

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PREFACE

The aim of this book is to emphasise the importance of understanding the *principles* of biology rather than to be a separate study of plant and animal *types*. The approach includes an elementary treatment of the chemistry, physics and mathematics essential to a proper understanding of biological *processes*. For additional exercises in answering questions, the reader is referred to the author's *Multiple Choice Questions in Biology and Human Biology* published by Heinemann Educational Books.

I should like to express my sincere thanks to Meinwen Parry, B.Sc., M.I.Biol., a biology teacher of long experience, for her critical reading of the typescript and many invaluable suggestions to improve the work, and to my son David Kilgour of New Zealand for his help and advice.

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The illustration of a white blood cell engulfing a bacterium which appears on the front of the dust jacket and cover was photographed with phase contrast by Gene Cox of Trowbridge and the publishers are grateful for permission to use it here.

O. F. G. K.

PART I

NATURE AND VARIETY OF LIVING ORGANISMS

CHAPTER 1

INTRODUCING BIOLOGY

1.1 WHAT IS BIOLOGY?

Biology is the study of *life* and living *organisms*, plants and animals on Earth *today*; it is also concerned with the life of the *past*, and very much concerned with life in the *future*.

Unlike chemistry, physics, mathematics and mineralogy, biology has no limits. Its areas of study penetrate into *biochemistry*, *biophysics*, *biometry* and *palaeontology*. As a consequence, some knowledge of physics, chemistry and mathematics is needed for a proper understanding of *modern biology* (Section 1.7 and Chapters 4 and 5).

The following is an outline summary of a typical syllabus for an examination at the ordinary level for biology:

(i) *nature* of living organisms, which is concerned with the basis of life in the *cell* and is of interest to the *microscopist*;
(ii) *variety* of life, which is concerned with a first-hand study of living organisms in the field or in the laboratory and is the interest of the *amateur naturalist* and others who wish to disentangle the complex web formed by over 1½ million different kinds (species) of plants and animals;
(iii) *functioning* and the life process occurring in living organisms as *individuals*;
(iv) *interdependence* of the different living organisms in *feeding*, their harmless and harmful relationships;
(v) *relationship* of plants and animals to where they *live*;
(vi) *man and nature*, and the effect of man on living organisms and where he lives.

1.2 WHAT USE IS BIOLOGY?

First and foremost biology should encourage a respect for *all* living organisms, and an understanding of how it affects our *own* way of life and other human beings.

Secondly, it is a form of scientific *exploration*, which develops skills of *observation, recording, experiment* and *calculation.*

Thirdly, it is a collection of useful *knowledge* for an understanding of sickness, health, feeding, conservation and a wiser use of natural reserves of food and materials.

Apart from being a leisure pursuit for the amateur naturalist, the study of biology can form the *basis* of a future job and may also be needed as an *entry requirement* to a profession or career.

1.3 HOW BIOLOGISTS WORK

Biologists have a *method* of working called the *scientific method* which all other scientists follow when tackling a problem; it involves the disciplines of *observation, recording, experiment* and *measurement*.

(a) Observation

This is the first step in any biological investigation, whether it is in observing the mating behaviour of birds or the growth of a flowering plant. If *measurement* can be used, the observation becomes *quantitative* and has a certain accuracy over *qualitative* observations.

(b) Repeated experiment

This is essential to make sure that a certain problem is not a *freak* event. The use of a *control experiment* is necessary to provide a condition which differs from the main experiment by *one* feature. For example, it is found that ripening rose-hip fruits contained in a muslin bag in a sealed container cause clear calcium hydroxide solution (lime water) to turn cloudy. In order to determine that the fruits *are* responsible, and not the muslin bag, a control experiment is set up. The control consists of an *empty* muslin bag, and this establishes that the rose-hip fruits cause cloudiness of the solution.

(c) Hypothesis

After repeated experimentation, a biologist will draw a conclusion from the experimental data and put forward an *explanation* of the facts that he has *observed.* Biologists will *publish* the results of their researches and any hypothesis in international journals of biology. Work by other biologists may *prove* or *disprove* the hypothesis and it then becomes the basis of a *theory*.

(d) Theory and law

Biological *laws* are drawn up when a theory has been *fully* proved, and is something which occurs without variation or failure and is acceptable to all biologists throughout the world.

In this way by *scientific method* in the work of many people throughout history, as observers, experimenters, theorists and researchers, the fundamental truths or *principles* of biological knowledge have been created.

1.4 BIOLOGICAL TERMS

Biology uses terms which have exact meanings or *definitions* often quite different from the same words used in everyday life. For example, *matter* is a form of energy which has weight or mass and occupies space. This is quite different from the everyday meaning of *pus, concern* or *business.*

Important biological terms are written in *italics* in the text and should be carefully noted. Many biological terms are derived from either Greek or Latin words, and many terms are made up of Greek *and* Latin words in mixed or *hybrid* terms, as in the following examples:

micronucleus = *micros* (Gk) + *nucleus* (L)
haemoglobin = *haima* (Gk) + *globulus* (L)
cnidocil = *cnido* (Gk) + *cilium* (L)

1.5 BIOLOGICAL INVESTIGATION

Biology is a first-hand study of living organisms in the field or laboratory.

(a) Fieldwork

Fieldwork can be done alone or by joining a field course at a Field Studies Centre.

(i) *Safety*

Plan well ahead. Avoid hazardous cliffs, quarries, etc. Notify others of your intentions and time of return. Respect the country code. Obtain landowner's permission.

(ii) *Equipment*

Hand lens, binoculars, camera, notebook, drawing pad, plaster of Paris for making casts, tape recorders and collection equipment (see Section 18.4).

(b) Laboratory work in general

Laboratory work can be done at home with a minimum of equipment.

(i) *Safety*

Do not eat, taste, drink, smoke or touch your lips when engaged in practical work.

Living organisms cause and transmit disease. Avoid handling *wild* animals, wear gloves.

Wash your hands after all laboratory work. Get medical attention for cuts, scratches and animal bites. Wear an overall.

Disinfect equipment and benches with 5% Lysol solution. Dispose of wastes by soaking in Lysol solution or by burning.

Microbe cultures must be handled with care as described in Section 19.2.

Label and date bottles, dishes and specimens.

(c) Dissection

It is illegal to perform dissection experiments on *living* organisms.

(i) *Equipment*

A wooden board, nail scissors, eyebrow tweezers, sharp pocket knife and needles mounted on wooden rods. Alternatively purchase a small dissection kit. A chemist's shop can supply small funnels, test tubes, beakers, petri dishes and a range of chemicals and reagent strips and test papers.

(d) Microscopy

A microscope, blank plain and cavity microscope slides, square cover slips. Obtainable second-hand or from an optician. Stains are available from chemist shops. Prepared slides from biological suppliers.

Draw two diagrams, first the *general* diagram or *plan* of tissues using low power, and then a detailed diagram of a small part of the tissues using high power.

(e) Experiments

A laboratory notebook is essential to record work. *The practical work should be done at the time coinciding with the theory*, as shown in the text. Keep the practical book carefully as it will be necessary to produce it for examiners if you proceed to advanced studies.

Set up a *main* and a *control* experiment.

Writing up experiments should follow a precise pattern as follows:

Title	To investigate, observe, or confirm . . . .
Method	This is a *brief* outline of materials, equipment, and the procedure used in the experiment.

Results	May be *qualitative*, shown by dissection diagrams, or colour changes, or presence or absence of chemical compounds, or *quantitative* measurements of some kind.
Conclusion	This should be brief and to the point. Indicate your *own* errors. Remember that every experiment may have different results, and not always go according to the book!

1.6 NUMBERS

Counting is used in finding the numbers in *populations* (see Section 20.1); it can be aided by means of a mechanical tally *counter*.

A single figure or number is called a *digit*, the digit nought, 0, is called zero.

One hundred = 100
One thousand = 1000
One million = 1000 000

A million can be written by the symbol M, 15 000 000 being written as 15 M.

Commas are not used in the SI system for large numbers, spaces are used instead [SI, International System of Units].

(a) Decimals

Numbers *less* than one, or unity, are written after a decimal point which is placed on the line . or above the line · as for example 0.65 or 0·65. A zero must be placed in front of the decimal point (e.g. 0.65) and should *not* be left as an *empty* space as in .65.

(b) Indices

The number 81 can be written as 9^2; this means the number 9 is multiplied by itself once, $9 \times 9 = 81$. Similarly 729 is 9^3 or the number 9 multiplied by itself twice, $9 \times 9 \times 9 = 729$. The number 9 is called the *base* and the small raised number the *index*:

$$10^2 = 10 \times 10 = 100$$
$$10^3 = 10 \times 10 \times 10 = 1000$$
$$10^4 = 10 \times 10 \times 10 \times 10 = 10\,000$$
$$10^5 = 10 \times 10 \times 10 \times 10 \times 10 = 100\,000$$
$$10^6 = 10 \times 10 \times 10 \times 10 \times 10 \times 10 = 1000\,000$$

The index number shows how many zeros are after the number 1.

Small numbers *less* than one or unity are also written using indices:

$10^{-1} = 0.1$
$10^{-2} = 0.01$
$10^{-3} = 0.001$
$10^{-4} = 0.0001$
$10^{-5} = 0.000\,01$
$10^{-6} = 0.000\,001$

The *minus* (–) sign is used to write small numbers less than 1. The index number shows the position of the number 1 after the decimal point.

(c) Prefixes

Prefixes are written as the first part of a compound word, e.g. *kilo*gramme or *micro*litre. Each prefix has its own symbol written as *capital* or *small* letters of our alphabet, with the exception of the Greek letter *mu* written in the Greek form of μ.

Table 1.1 summarises the important prefixes and their symbols, all of which are encountered in biology.

It is important to use capital or small letters correctly; for example, M is a million, whilst m is only one-thousandth part of 1.

1.7 BIOLOGICAL CALCULATIONS

(a) Ratios

This is the numerical *relation* that one quantity bears to another. For example, out of a population of sweet pea plants, 428 have red flowers and 152 have white flowers. The ratio is calculated by dividing the *smallest* number into the other number(s); the smallest number becomes unity:

$$428 \div 152 = \frac{428}{152} = \frac{2.8}{1} = 2.8$$

There is a ratio of 2.8 red flowers to *each* white flower, and this is written as 2.8:1. The : symbol means 'to'; so 2.8 to 1 is the same as 2.8:1.

Numbers can be *rounded up* to the nearest *whole* number. Consequently 2.8 can be rounded up to 3, making the ratio 3:1.

(b) Percentages

This is a fraction with the denominator of 100; or a percentage is the part of a hundred.

Decimals can be expressed as percentages by multiplying by 100 and writing the symbol % after :

$$0.78 \text{ is equal to } 0.78 \times 100 = 78\%$$

Large numbers can be converted to percentages. Using the red and

Table 1.1 *numbers: their prefixes, index notation and decimal equivalents*

	Prefix	*Symbol*	*Number*	*Fraction*	*Index*
Very	mega-	M	1000 000	one million	10^6
large	kilo-	k	1000	one thousand	10^3
numbers	hecto-	h	100	one hundred	10^2
	deca-	da	10	ten	10^1
Unity			1	one	10^0
	deci-	d	0.1	one-tenth	10^{-1}
	centi-	c	0.01	one-hundredth	10^{-2}
Very	milli-	m	0.001	one-thousandth	10^{-3}
small	micro-	μ	0.000 001	one-millionth	10^{-6}
numbers	nano-	n	0.000 000 001	one-thousand-millionth	10^{-9}

Examples

$$5 \times 10^9 = 5 \times 1000\,000\,000 = 5000\,000\,000$$

$$3 \times 10^6 = 3 \times 1000\,000 = 3000\,000$$

$$2.2 \times 10^5 = 2.2 \times 100\,000 = 220\,000$$

$$0.3 \times 10^{-7} = 0.3 \times \frac{1}{10\,000\,000} = 0.000\,000\,03$$

$$0.5 \times 10^{-4} = 0.5 \times \frac{1}{10\,000} = 0.000\,05$$

white sweet pea flower figures, the percentage of red and white flowers can be calculated:

$$\frac{\text{number of certain quantity}}{\text{total quantity}} \times 100 = \text{percentage}$$

$$\text{red flower percentage} = \frac{428}{428 + 152} \times 100 = 73.79\%$$

$$\text{white flower percentage} = 100 - 73.79\% = 26.21\%$$

(c) Averages

One kind or species of living organism can show a great *variation* in a certain measured quantity such as height, length or weight. The *average* value can be calculated by *adding* all the values together and dividing by the total number of individuals:

$$\text{average} = \frac{\text{total of all values}}{\text{total } \textit{number} \text{ of individuals}}$$

For example, *eight* seeds of a plant have the following weights: 8, 7, 6, 4, 9, 3, 5, 7 grammes (g). So

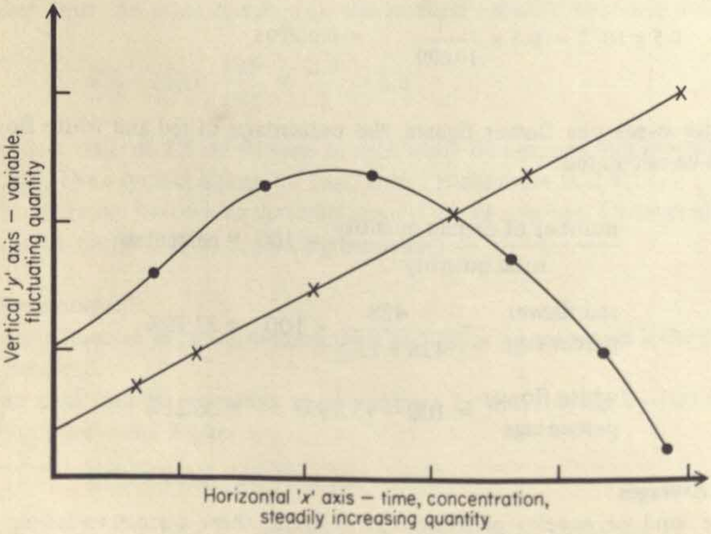
$$\begin{aligned}\text{average weight} &= (8+7+6+4+9+3+5+7) \div 8 \\ &= 49 \div 8 \\ &= 6.125 \text{ g}\end{aligned}$$

1.8 **GRAPHS**

(a) Graphs

A graph is a diagram which shows the relationship between one *changing* or variable quantity and another (Fig. 1.1). For example, the seed *weight* in Section 1.8 showed variation or was a variable quantity; another variable quantity would be the seed *volume*. Using these *two* quantities, a graphical relationship could be shown.

fig 1.1 *method of graph construction*



Construction of graphs

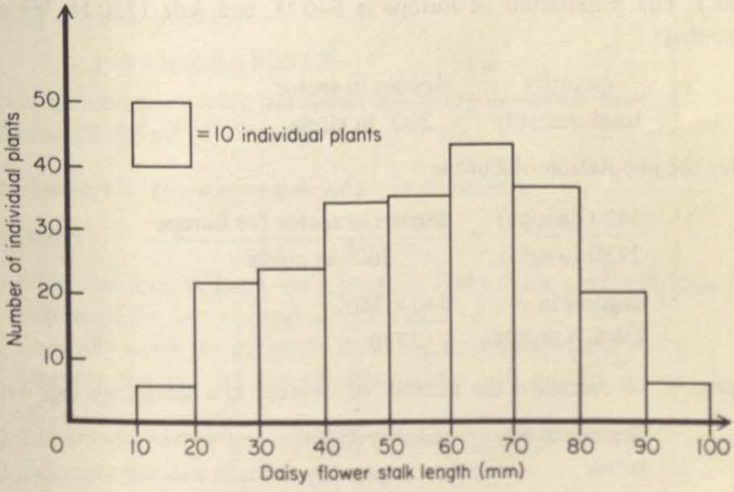
(i) Use squared graph paper and carefully count the number of *large* squares, and how many *small* squares make a large square.
(ii) Draw two lines at right-angles to each other as *axes*, the vertical line ↑ is called the *y* axis, the horizontal line → is the *x* axis.
(iii) Decide on a *scale* and mark off on the axis at regular intervals. Write in the name of the fluctuating quantity, length or weight, on the vertical axis; it is usual to enter *time* or *rate*, the steadily increasing quantity, on the horizontal axis.
(iv) Make certain the graph *fills* the squared paper.
(v) Plot each point with a pencilled dot or small cross.
(vi) Connect all the points, dots or crosses, with either a *straight* line or a *curved* line, to suit the graph. Straight lines are produced by *directly proportional* quantities, whilst *curves* may show a maximum and minimum relationship.

(b) Histograms

A histogram is another diagram showing a *frequency distribution* by means of *rectangles* or *bars* of a certain area or height (Fig. 1.2). For example, the number of sweet pea plants with red and white flowers can be shown on a histogram.

The histogram is constructed on graph paper. The range of measure-

fig 1.2 *an example of a histogram: daisy (*Bellis *sp.) flower stalk length*

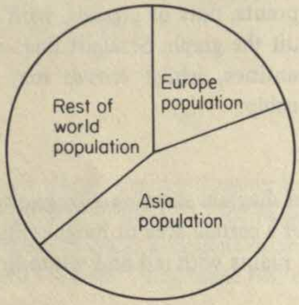


ment, colour, height or weight, etc., is shown on the ***horizontal axis***, whilst the number or frequency of a particular measurement is shown on the *vertical axis.*

(c) Pie diagrams

A pie diagram is a *circular* diagram with quantities shown as occupying different sectors or pie slices (Fig. 1.3).

fig 1.3 *an example of a pie diagram: world population*



A circle is composed of 360 degrees; sectors can be measured with a *protractor*.

The following example shows how a pie diagram is constructed. The total world population is 2730 M (million); let this equal 360 degrees (360°). The population of Europe is 540 M, and Asia 1220 M. We can write that

$$\frac{\text{quantity}}{\text{total quantity}} = \frac{\text{degrees in sector}}{360^\circ \text{ in circle}}$$

so for the population of Europe

$$\frac{540\ (\text{Europe})}{2730\ (\text{world})} = \frac{\text{degrees in sector for Europe}}{360^\circ \text{ in circle}}$$

$$\begin{matrix}\text{degrees in}\\ \text{Europe sector}\end{matrix} = \frac{540 \times 360^\circ}{2730} = 71^\circ$$

In general, to calculate the number of degrees in a sector, we can write

$$\begin{matrix}\text{degrees in a}\\ \text{sector}\end{matrix} = \frac{\text{quantity} \times 360}{\text{total quantity}}$$

and so

$$\text{degrees in Asia sector} = \frac{1220 \times 360}{2730} = 160^\circ$$

Using a protractor, a circle is drawn with one sector for Europe measuring 71° and one sector for Asia measuring 160°; the rest of the world population will be $360 - (160 + 71) = 129^\circ$.

Pie diagrams can be constructed from *percentage* values, assuming $100\% = 360^\circ$, using

$$\text{degrees equivalent to certain percentage} = \frac{\text{percentage value} \times 360^\circ}{100}$$

1.9 MEASUREMENT OF LENGTH

The unit of length is called the *metre* (symbol m), and is divided into one hundred *centimetres* (cm). Each centimetre is divided into ten *millimetres* (mm). Note that cm and mm are never written as cms or mms.

$$1 \text{ m} = 100 \text{ cm} = 1000 \text{ mm}$$

Small measurements of length less than a millimetre are in *micrometres* (μm) and *nanometres* (nm). Cells are measured in micrometres, and molecules and atoms in nanometres.

$$1 \text{ mm} = 1000\ \mu\text{m} = 1000\,000 \text{ nm}$$

1.10 MEASUREMENT OF AREA

Area is the measurement of surface calculated by product of length multiplied by width or breadth:

$$\text{area} = \text{length} \times \text{breadth}$$

Area is measured in *square* metres or m^2, using the index number 2. The *hectare* is $10\,000 \text{ m}^2$ (2.47 acres).

Experiment 1.1 *to measure area of a foot or hand*

Procedure

(i) Place the foot or hand on a sheet of fairly thick card and trace the *outline* of the foot or hand onto the card.
(ii) Carefully weigh the complete sheet and record its weight as A g.
(iii) Measure the area of the complete sheet and record its area as B cm^2.
(iv) Cut out the outline and carefully measure its weight as C g.
(v) Calculate the area of the foot or hand as follows:

The sheet weighing A g has area B cm^2.
Therefore the outline weighing C g has an area of

$$\frac{C\ \mathrm{g} \times B\ \mathrm{cm}^2}{A\ \mathrm{g}} = \quad \mathrm{cm}^2$$

Observations

The *surface area* of living organisms is difficult to measure *directly* since they have *irregular* body shape.

1.11 MEASUREMENT OF VOLUME

Volume is the amount of space occupied by matter. The unit of volume is called the cubic metre (m^3). The most commonly used unit is the *litre*(1), divided into one thousand *millilitres* (ml).

$$1\ \mathrm{l} = 1000\ \mathrm{ml}$$

An alternative to the millilitre is the *cubic centimetre* (cm^3).

$$1\ \mathrm{l} = 1000\ \mathrm{cm}^3 = 1000\ \mathrm{ml}$$

Volume is usually measured by means of *measuring cylinders*, and in addition pipettes, burettes and graduated flasks are also used. Measuring syringes are also employed.

Experiment 1.2 *to measure volume of irregularly shaped bodies*

Procedure

(i) Half fill a large measuring cylinder (500 cm^3) with water and note the level as A cm^3.
(ii) Lower a potato into the water until it is completely immersed. Note the new water level as B cm^3.
(iii) Calculate the volume of the potato from

$$B\ \mathrm{cm}^3 - A\ \mathrm{cm}^3$$

1.12 MEASUREMENT OF MASS/WEIGHT

Weight is the pull of *gravity* on a body. Since gravity varies in different parts of the Earth, it will mean that weight can vary from place to place, and be greatly decreased in outer space.

Mass is the quantity of matter in a known *volume* of substance, and consequently mass does not change. For general purposes, weight and mass are equal.

Mass is measured by means of a *balance*. The unit of mass is the *kilogramme* (kg); this is divided into one thousand *grammes* (g).

1 kg = 1000 g

Weights less than 1 g are encountered in biological measurement. A gramme can be divided into one thousand *milligrammes* (mg).

1 g = 1000 mg

Each milligramme is divided into one thousand *microgrammes* (μg)

1 mg = 1000 μg

Similarly,

1 g = 1000 mg = 1000 000 μg

Table 1.2 summarises the important units of measurement encountered in biology.

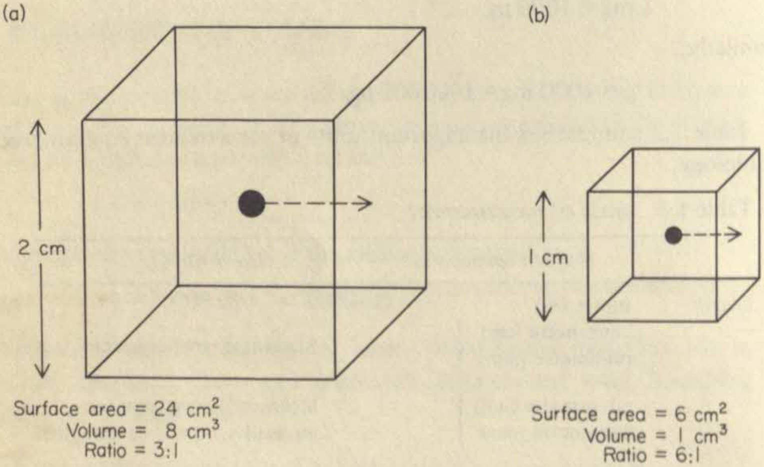
Table 1.2 *units of measurement*

	Units in common use	*Use in biology*
Length	metre (m)	
	centimetre (cm) millimetre (mm)	Measuring most organisms
	micrometre (μm) nanometre (nm)	Measuring micro-organisms, molecules, atoms, wavelengths
	1 m = 100 cm 1 cm = 10 mm = 10 000 μm = 10 000 000 nm	
Area	square metre (m^2) square centimetre (cm^2)	Measuring surface area of most organisms
	square millimetre (mm^2) 1 cm^2 = 100 mm^2	Measuring surface area of micro-organisms
Volume	cubic metre (m^3) litre (l)	
	cubic centimetre (cm^3) millilitre (ml)	Most volume measurements
	1 l = 1000 ml 1 ml = 1 cm^3	
Mass	kilogramme (kg)	Weighing large organisms
	gramme (g)	Weighing small organisms and food portions
	milligramme (mg)	Dietary minerals and vitamins, B, C
	microgramme (μg)	Dietary vitamins A, D
	1 kg = 1000 g 1 g = 1000 mg = 1000 000 μg	

1.13 SURFACE AREA RELATIONSHIP

An important mathematical rule states that as the *volume* of an object *increases*, its *ratio* of surface area to volume *decreases* (Fig. 1.4).

fig 1.4 *relationship between surface area and volume. As the body* increases *in size the amount of surface compared to volume* decreases



This is of great importance in biology and can be stated in another simple way, i.e. that *small* organisms have *more area* of body surface relative to their volume compared to *large* organisms.

The relationship between surface area and volume can be shown with reference to *cubes* of a regular shape.

(i) A cube has *six* surfaces, each with an *area* measured from length × breadth.

(ii) The *volume* of a cube will be the product of length × breadth × height.

The relationship between cubes of different surface area and volume is given in Table 1.3. A small cube with sides measuring 1 cm will have almost *ten* times the relative amount of body surface as the large cube with sides measuring 10 cm.

Another important mathematical feature is that the *distance* from the *centre* of a small cube or organism to the body surface is much less than for a larger cube or organism body.

This relationship between surface area and volume will be repeatedly stressed in many aspects of biological studies, and should be understood before proceeding further.

Table 1.3 *the relationship between cubes of different surface area and volume*

Length of cube side (cm)	*Area of one side* (cm^2)	*Total surface area of six sides* (cm^2)	*Volume of cube* (cm^3)	*Ratio of surface area to volume*	*Number of cm^2 of area to each cm^3 of volume* (cm^2/cm^3)
1	1	6	1	$\frac{6}{1} = 6$	6
2	4	24	8	$\frac{24}{8} = 3$	3
4	16	96	64	$\frac{96}{64} = 1.5$	1.5
10	100	600	1000	$\frac{600}{1000} = 0.6$	0.6

1.14 QUESTIONS

1 Plot the following data, showing changes in body weight of a locust over a period of time, on a graph.

Day	1	3	6	9	12	15	18	21	24
Body weight (mg)	100	100	200	230	350	530	600	760	1200

2 Plot the following data, showing changes in height of boys and girls during growth from age 1 to 15 years, on a graph. Plot the two sets of data on the same graph.

Age		1	2	3	4	5	6	7	8
Height (cm)	Boys	75	87	96	103	111	117	124	130
	Girls	74	86	95	103	109	115	122	128
Age		9	10	11	12	13	14	15	
Height (cm)	Boys	135	140	144	149	155	162	167	
	Girls	132	138	144	151	157	159	161	

3 The following table is a frequency distribution for young men aged 21 years:

Height (cm)	*Number of men*
150–154	5
155–159	18
160–164	42
165–169	27
170–174	8

(a) Construct a *histogram* showing the distribution of height amongst the men.

(b) Calculate the *percentage* of men in each height group.

(c) Construct a *pie diagram* showing the distribution of height, from the percentage in each group.

4 The total world population is 2730 M. The figures for each area are given as follows:

Area	*Population in millions*
America	510
Africa	460
Europe	540
Asia	1220

(a) Calculate the *percentage* in each area.
(b) Construct a *pie diagram* showing this information.
(c) Draw a *bar diagram* on a large scale to exaggerate this information.

5 The following shows the percentage composition of certain foods. Draw a pie diagram and a histogram to display the composition in each case.

Food	*Water* (%)	*Protein* (%)	*Lipid* (%)	*Carbohydrate* (%)
Bread	46	9	3	42
Cheese	40	26	34	0
Milk	88	3	4	5

CHAPTER 2

VARIETY OF LIVING ORGANISMS

2.1 INTRODUCTION

The study of living organisms in their natural surroundings or environment is called *natural history*. An important aspect of this study is *external morphology* or the science of external *form* of organisms. A *naturalist* will observe and record the *external* appearance and relative positions of body parts of an organism. A knowledge of the *internal* structure of organisms will involve the study of *anatomy* as outlined in Chapter 3.

Drawing is an important part of biological study. The biological drawing is called a *line diagram*; it is *not* a sketch, is not artistic nor three-dimensional and does not require elaborate shading.

Draw all diagrams in *pencil*, and ensure that all parts shown are in *proportion* to each other; check with a ruler if necessary.

Label the diagram with neat labelling in pencil or ink, and connect the label to the diagram with a pointer line.

2.2 THE SPECIES

A *species* is a group of individuals able to breed amongst themselves. For example, the buttercup is a species able to interbreed with other buttercup plants, but unable to breed with a daisy which is another distinct species. Every *individual* organism is therefore a member of a species.

Members of a species will look alike and have a similar external morphology, making it easy to identify a species of cat or dog, dandelion or daisy.

2.3 NAMING THE ORGANISM – NOMENCLATURE

A species of organism will have a *common name* in any language; a species will have *more* than one common name – for example, a flower is called grannies bonnets by certain folk and columbine by others in the United Kingdom. Such common names are misleading and would not be understood on an international basis.

Linnaeus (1707-1778), a botanist, introduced the *binomial nomenclature* system for naming all plant and animal species with *two* latinised names, giving every species an *official scientific name*. For example, modern man is *Homo sapiens*, which in Latin means 'wise man'. Official scientific names for a species are decided by a committee of *International* Rules of Nomenclature. This ensures that the name of the species will be written in the same way and understood by naturalists and biologists throughout the world.

The scientific name is always underlined or printed in *italics*. The first name is the generic name or *genus*, and the second name is the specific name or *species*. The domestic cat is called *Felis domesticus*. The generic name starts with a capital or large letter, and the specific name starts with a small or lower-case letter.

2.4 CLASSIFICATION OF ORGANISMS

John Ray (1627-1705), a naturalist, first introduced the term *species* and produced a system of plant and animal classification. The science of classifying organisms according to resemblances and differences in their *morphology* is called *classical taxonomy*. When structural features are so similar as to be almost indistinguishable, it may be necessary to classify on the basis of *biochemical* tests.

(a) Kingdoms

Organisms are classified scientifically into a series of categories or groups. The two most important groups are the plant and animal *kingdoms*. The animal kingdom is composed of about *one million* different species, and the plant kingdom of about *half a million* different species.

Table 3.3 summarises some of the main differences between plants and animals, and shows how a species is allocated a place in one or other *kingdom*. Some species do not fit into a particular kingdom, for example bacteria and viruses. Bacteria are considered by some biologists to be plants and by others to be animals, whilst still others classify them apart from either kingdom.

(b) Phylum

The animal kingdom is composed of *ten* large phyla (the plural of phylum is phyla), ranging from the phylum 'Protozoa' to the phylum 'Chordata'.

The plant kingdom is composed of *six* large phyla, ranging from the phylum 'Bacteria' (as we consider them as plants) to the phylum 'Spermaphyta'.

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Each phylum is composed of plants or animals that share a few basic *characters*, which are *heritable* and can be passed on to offspring of the same species. Details of the main characters of organisms in a phylum are described in the following sections.

(c) Further classification

Each *phylum* is composed of one or more *classes*. For example, the phylum 'Chordata' includes the classes of fish, amphibia, reptiles, birds and mammals. Members of a class will share *more* characters.

Each *class* is composed of one or more *orders*. For example, the class 'mammals' is composed of the orders of insect-eaters, hoofed animals, bats and apes or primates.

Each *order* is composed of one or more *families*. The flowering plants are important examples in having 123 different families ranging from the buttercup family 'Ranunculaceae' to the grass family 'Gramineae'.

Each *family* will be composed of the *genus* and *species* giving the name of the individual organism.

Table 2.1 summarises the classification of a meadow buttercup and a human being. The different classification groups, phylum, class, etc., are called *taxons*.

Table 2.1 *Classification of a meadow buttercup and a human being*

Taxon	*Meadow buttercup*	*Human being or modern man*
Kingdom	plants	animals
Phylum	Spermaphyta	Chordata
Class	Angiospermae	Mammalia
Order	Ranales	Primates
Family	Ranunculaceae	Hominidae
Genus	*Ranunculus*	*Homo*
Species	*acris*	*sapiens*

2.5 CLASSIFICATION OF THE PLANT KINGDOM

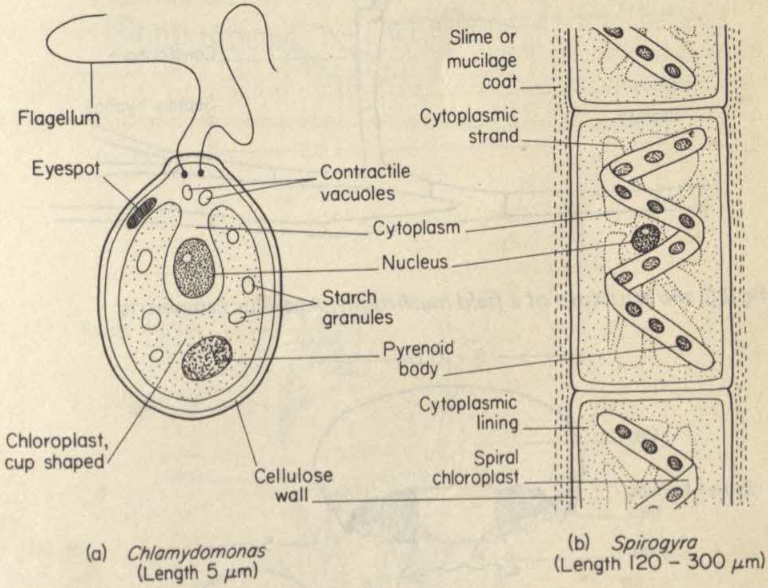
(a) Phylum Bacteria

(See Section 19.3.) Found in soil, air and water. Microscopically small, with a simple cell structure, spherical, cylindrical, comma-shaped and spiral-shaped. Some are green and thus allow bacteria to be classed as plants.

(b) Phylum Algae

(See Sections 3.5 and 15.2.) About 5% of all known plant species. Found in fresh water, sea water and damp areas. Mainly green plants, though some are brown or red, with a variety of *forms*; microscopically small *Spirogyra* and *Chlamydomonas* (Fig. 2.1), and also include *phytoplankton* or diatoms and desmids. Large algae include seaweeds. The plant body is called a *thallus*, being without a root, stem or leaf.

fig 2.1 *structure of the unicellular algae: (a)* Chlamydomonas *sp. and (b)* Spirogyra *sp.*



(a) *Chlamydomonas* (Length 5 μm)

(b) *Spirogyra* (Length 120 – 300 μm)

(c) Phylum Fungi

About 18% of all plant species are fungi. Found mainly on land. They are *non-green* plants with the plant body composed of interwoven *hyphae* forming a *mycelium*. This may resemble a mould or large mushroom. Moulds include *Mucor, Penicillium* Fig. 2.2), *Pythium*, mildew *Erysiphe* and yeast *Saccharomyces*. The larger fungi include the field mushroom (Fig. 2.3) and the poisonous Death Cap mushroom.

fig 2.2 *structure of the blue-green mould,* Penicillium *sp.*

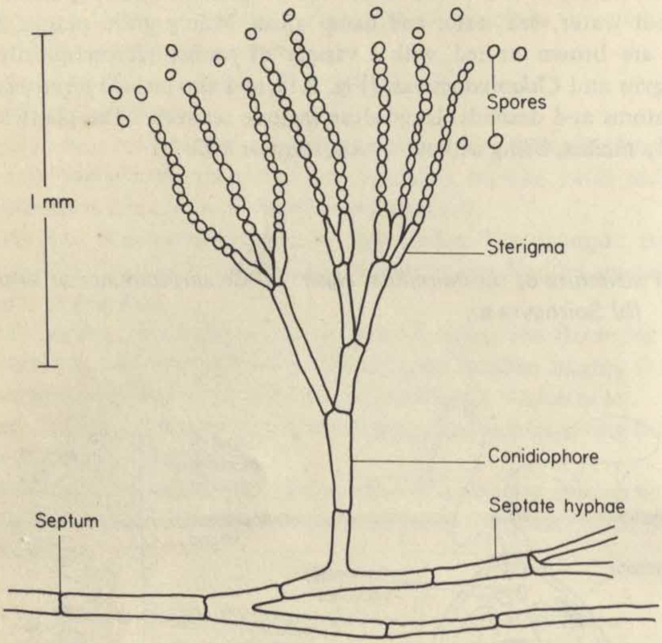


fig 2.3 *the structure of a field mushroom,* Agaricus campestris

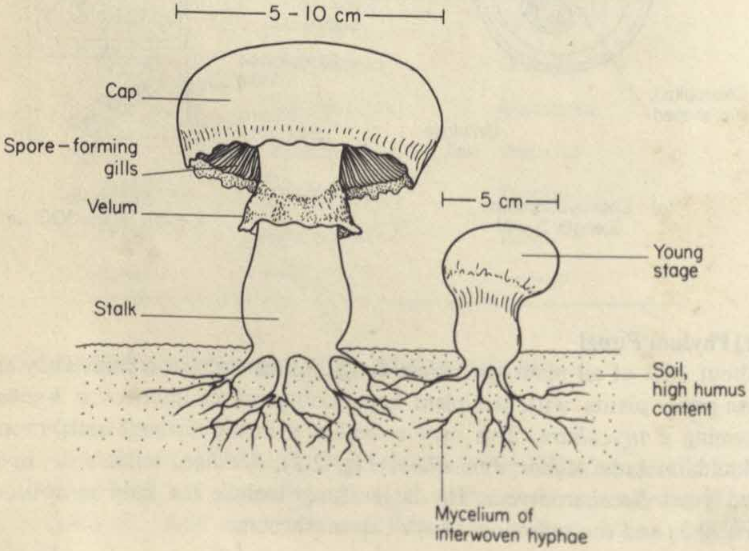
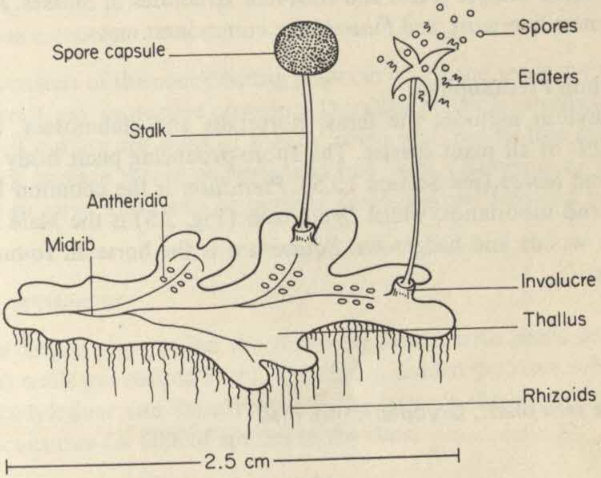
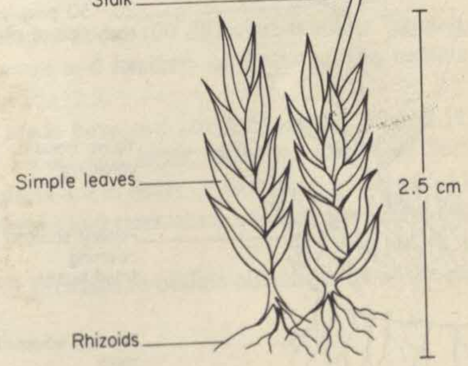


fig 2.4 *examples of Tryophyta: (a) the liverwort,* Pellia *sp. and (b) moss,* Funaria *sp.*



(a) *Pellia*



(b) *Funaria*

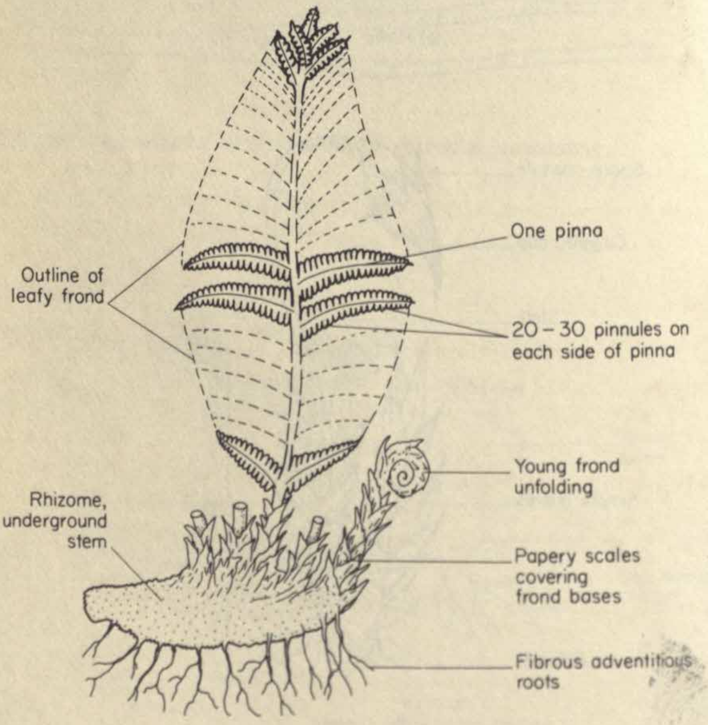
(d) Phylum Bryophyta

This includes the liverworts and mosses (Fig. 2.4), and forms about 6% of all plant species. Found on land in wet places, marshes and bogs. The plant body or thallus may be flattened and leaf-like in liverwort (see Section 3.6) or may show simple leaves and root-like structures in mosses. *Pellia* is the commonest liverwort, and *Funaria* the commonest moss.

(e) Phylum Pteridiophyta

This phylum includes the ferns, horsetails and clubmosses, and forms about 2% of all plant species. The spore-producing plant body has *roots*, *stems* and *leaves* (see Section 15.5). *Pteridium* is the common bracken of woods and moorlands, whilst *Dryopteris* (Fig. 2.5) is the Male Fern common in woods and hedgerows. *Equisetum* is the horsetail found in damp marshes.

fig 2.5 *a fern plant,* Dryopteris filix-mas


One pinna
Outline of leafy frond
20 – 30 pinnules on each side of pinna
Young frond unfolding
Rhizome, underground stem
Papery scales covering frond bases
Fibrous adventitious roots

(f) Phylum Spermaphyta

This phylum includes all plants which form *seeds* and accounts for about 65% of plant species. Some have *cones* in conifer plants; the majority have *flowers* in flowering plants.

(i) *Class Gymnosperms*

This class consists of the cone-bearing plants in which the *seeds* are formed naked without any protective covering. Dust-like pollen is produced by a *male* cone. Conifers are *trees* or *shrubs*, often with needle-like evergreen leaves. They include spruce or christmas tree, pine, *Cupressus* or juniper, and *Taxus* or yew. The *Larix* or larch is *deciduous* and loses its leaves in autumn.

(ii) *Class Angiosperms*

This is the largest class, called the *flowering plants*, with seeds protected within *fruit* walls (see section 15.6). The class is divided into two *subclasses*, the Monocotyledons and Dicotyledons. The latter is the more numerous species, accounting for 60% of species in the class.

(1) Subclass Monocotyledons

This includes over 20 families including grasses or *Gramineae*, orchids or *Orchidaceae*, lilies or *Liliaceae*, irises or *Iridaceae* and daffodils or *Amaryllidaceae*. A grass is shown in Fig. 2.6.

The seeds have one *cotyledon* (see Section 11.4). The *leaves* are usually long and narrow with *parallel* veins (see Section 6.4). Most of the flower parts are in *threes*. Almost all are herbaceous with fibrous roots.

(2) Subclass Dicotyledons

This includes about 100 different families: legumes or *Leguminosae*, roses or *Rosaceae* and heathers or *Ericaceae*, to name a few. A wallflower is shown in Fig. 2.7.

The seeds have *two* cotyledons (see Section 11.4), and the leaves are usually *broad* and *lobed*, with *net* veins (see Section 6.4). Most of the flower parts are in fours or fives (see Section 15.6). Dicotyledons include herbs, shrubs and trees which at some time show a tap root.

Table 2.2 provides an outline classification of the plant kingdom.

fig 2.6 *a monocotyledon flowering plant, the foxtail grass,* Alopecurus *sp.*

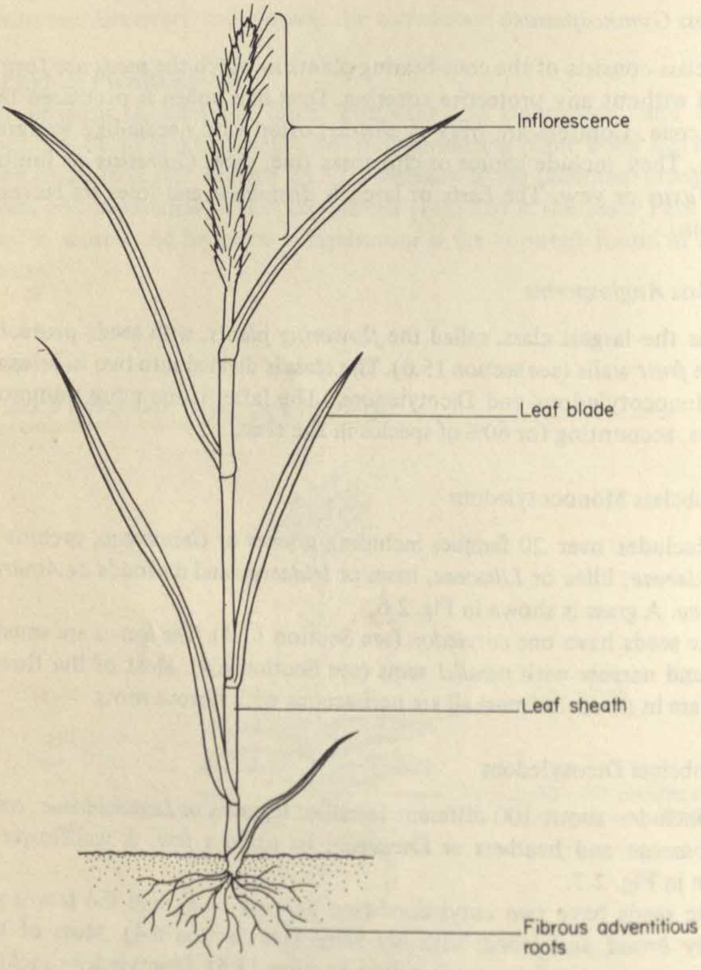


fig 2.7 *a dicotyledon herbaceous flowering plant, the wallflower,* Cheiranthus *sp.*

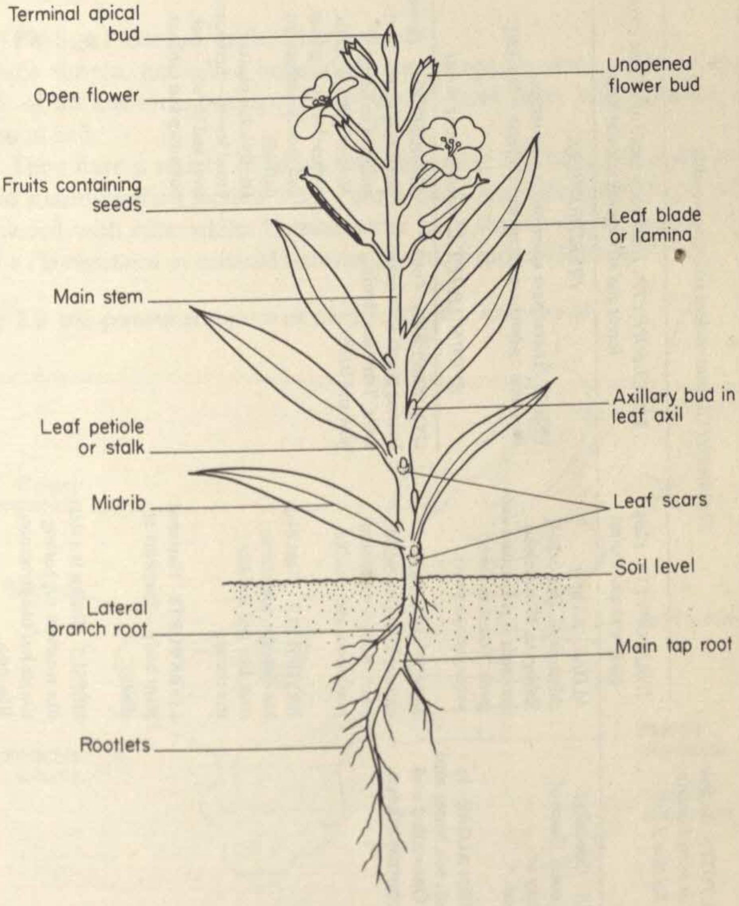


Table 2.2 *tabular survey – plants*

PROCARYOTES: no true nucleus or mitochondria (see Section 3.3)	*EUCARYOTES: true nucleus and mitochondria*		
	THALLOPHYTA: plant body a simple thallus	*TRACHEOPHYTA: plant body made up of true roots, leaves and stems with vascular tissue*	
BACTERIA One-celled bacilli and cocci. Cause of disease, decay or fermentation.	ALGAE All have chlorophyll. One-celled: *Spirogyra*. Multicellular: seaweeds – red, brown and green. Found in fresh water and sea water.	*PTERIDIOPHYTA* FERNS Leaves have spore-making sporangia. Perennial underground stem and rhizome – bracken.	
		SPERMAPHYTA: seed-forming plants	
BLUE-GREEN ALGAE In fresh water, sea water and dry land. One-celled and perform photosynthesis.	FUNGI All without chlorophyll. One-celled: yeast. Body a mycelium: mushroom and moulds.	GYMNOSPERMS Cone-bearing plants with *naked* seeds. Trees and shrubs, pine and larch.	ANGIOSPERMS *Flower*-producing plants. Seeds enclosed in fruits. *Monocotyledon* plants: narrow leaves – grasses, and mostly herbaceous – daffodil. *Dicotyledon* plants: broad leaves – herbaceous, trees and shrubs – oak, buttercup and cabbage.
	BRYOPHYTA Plant body has *rhizoids*, sometimes stem-like and leaf-like structures.		
	LIVERWORTS Flattened plant body – liverwort or thallus.		
	MOSSES Thallus is a stem-like structure supporting simple leaf-like structures. Bog moss.		

2.6 CLASSIFICATION OF THE ANIMAL KINGDOM

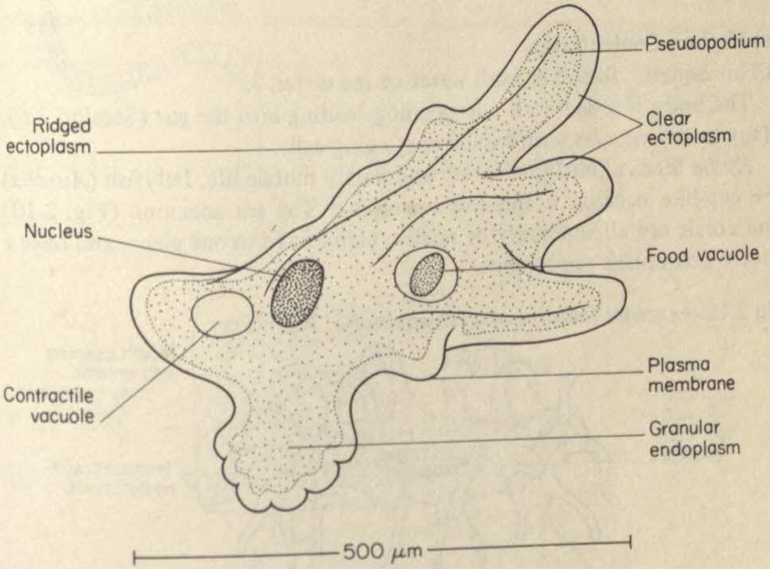
There are two collective terms used concerning animals, the *invertebrata* (or animals without vertebral columns) and the *vertebrata* (which is a sub-phylum, and includes all animals with a vertebral column). The phyla of the invertebrata are given in (a) - (i) and the vertebrata in (j).

(a) Phylum Protozoa, or the 'first animals'

These simple, one-celled organisms, microscopic in size, comprise about 5% of all known animal species. Found in fresh water and sea water and also in soil.

They have a variety of forms: *Amoeba* (Fig. 2.8) has an irregular shape and *pseudopodia* (Section 3.5); *Paramecium* has a definite shape and is covered with *cilia;* whilst *Trypanosoma* has a *flagellum* (see Section 14.5). The *Plasmodium* or malarial parasite produces spores (Section 19.6).

fig 2.8 *the general structure of the protozoan,* Amoeba *sp.*

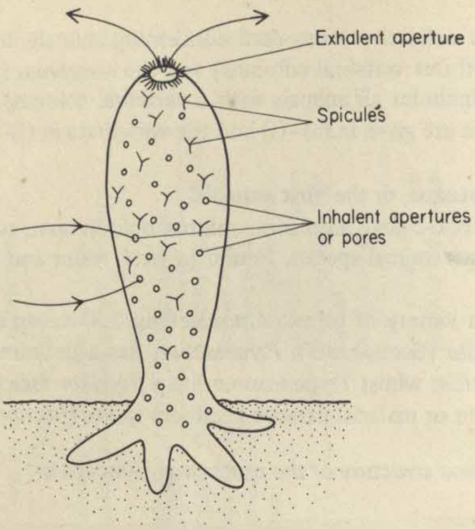


(b) Phylum Porifera, the 'porous sponges'

These organisms are found in sea water and fresh water.

The body has *many* openings or pores for *entry* of water, and it also has *one* large pore for exit of water (Fig. 2.9). All sponges are sedentary, resembling most plants in their inability to move. The bath sponge is *Euspongia*. (The bath *loofah* is part of a plant.)

fig 2.9 *morphology of a sponge*



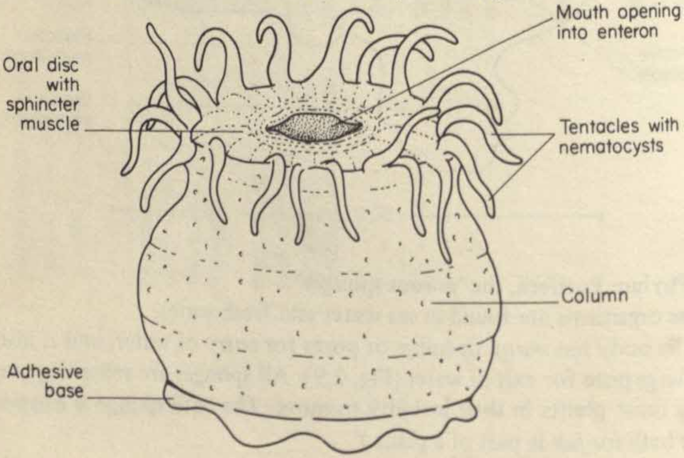
(c) Phylum Coelenterata

All are aquatic, found in fresh water or sea water.

The body is a *sac* with one opening leading into the *gut* (Section 3.6). Many have *tentacles* with explosive stinging cells.

Hydra leads a partly sedentary and partly mobile life. Jellyfish (*Aurelia*) are cup-like organisms and free-swimming. The sea anemone (Fig. 2.10) and corals are all sedentary or *sessile*, being fixed to one place, and have a pretty flower-like appearance.

fig 2.10 *external features of a sea anemone,* Actinia *sp.*

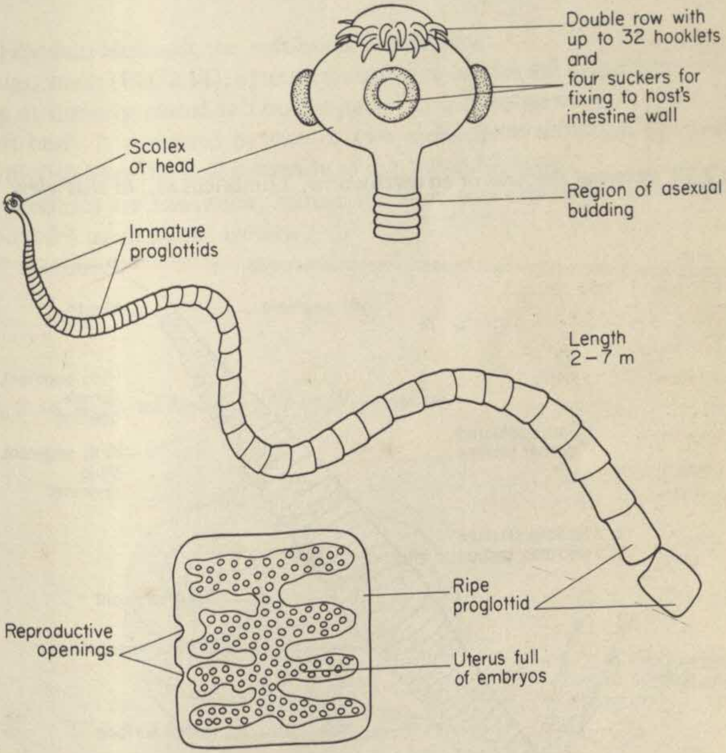


(d) Phylum Platyhelminthes, the 'flat worms'

The distinct multicellular bodyform (namely a *flattened* body) identifies members of this phylum. Flattening gives the body a *dorsal* (or back) side, and a *ventral* (or belly) side. There is usually a mouth opening.

Some flatworms are found in fresh water, for example *Planaria*. The tapeworm, *Taenia* (Fig. 2.11), and the liver-fluke, *Fasciola*, are *parasites* on vertebrate animals.

fig 2.11 *external features of a pork tapeworm,* Taenia solium


Double row with up to 32 hooklets and four suckers for fixing to host's intestine wall
Scolex or head
Region of asexual budding
Immature proglottids
Length 2–7 m
Ripe proglottid
Reproductive openings
Uterus full of embryos

(e) Phylum Nematoda, the 'round worms'

These organisms have a narrow thread-like body tapered at each end. One end, with the mouth, is the *anterior* or head end. The *posterior* end is the part with the tail. The body is covered with a thick elastic *cuticle.*

Some roundworms (Fig. 2.12) are aquatic, many live in the soil, and others are parasites on other organisms. The threadworm, *Enterobius*, is found in young children.

fig 2.12 *external features of a roundworm,* Ascaris *sp.*

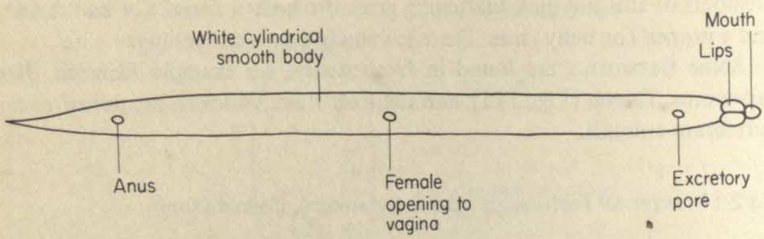
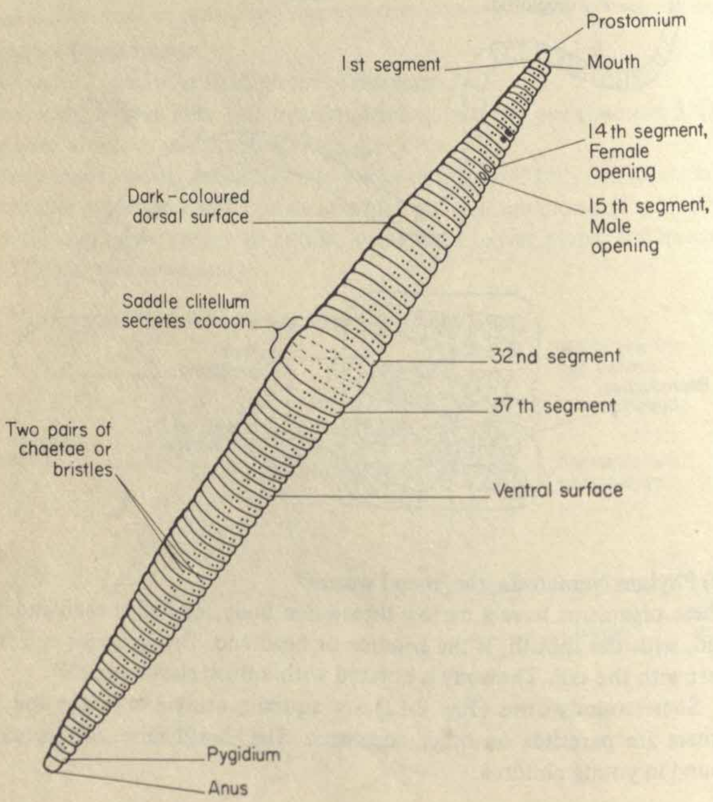


fig 2.13 *external features of an earthworm,* Lumbricus *sp., in side view*


Prostomium
1st segment
Mouth
14th segment, Female opening
Dark-coloured dorsal surface
15th segment, Male opening
Saddle clitellum secretes cocoon
32nd segment
37th segment
Two pairs of chaetae or bristles
Ventral surface
Pygidium
Anus

(f) Phylum Annelida, the 'ringed worms'

Annelid worms have the distinctive *segmented* appearance due to *metameric segmentation*. This is the division of the body internally and externally into *segments* by means of internal partitions or septa (the singular of which is septum), along the whole body length. Some annelid worms like the earthworm (Fig. 2.13) have *chaetae* or bristles on each segment.

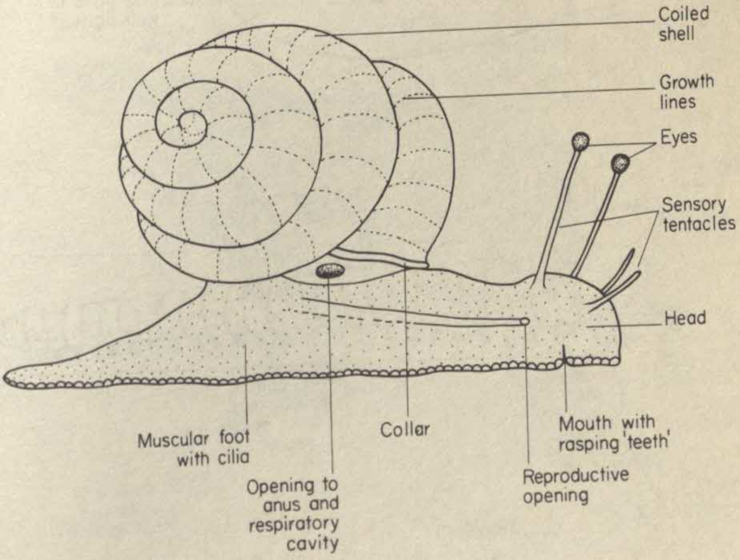
The earthworm, *Lumbricus*, is found in soil, whilst the lugworm, *Arenicola*, is found in sea sand. The medicinal blood-sucking leech, *Hirudo*, is found in fresh water.

(g) Phylum Mollusca, the 'soft-bodied' organisms

Slugs, snails (Fig. 2.14), oysters, mussels and cockles are organisms consisting of dorsally placed soft bodies joined to *one* ventral muscular *foot*. The soft body is protected by one or two *shells*. Some molluscs, squids and cuttlefish have the shell internally as the 'cuttlefish bone'.

Molluscs are freshwater, marine and terrestrial organisms and comprise about 5% of all animal species.

fig 2.14 *external features of a snail,* Helix *sp.*



(h) Phylum Arthropoda, the jointed limbed organisms

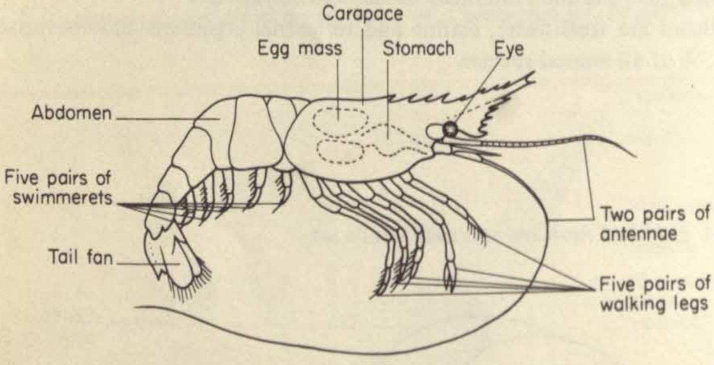
This phylum includes over 80% of all animal species. The members have the distinctive *jointed* legs or *appendages*, together with a tough outer *cuticle* of chitin (see Section 14.2) which is shed during moulting. Many have a *head* and special *mouthparts*.

The following are the important classes of arthropoda.

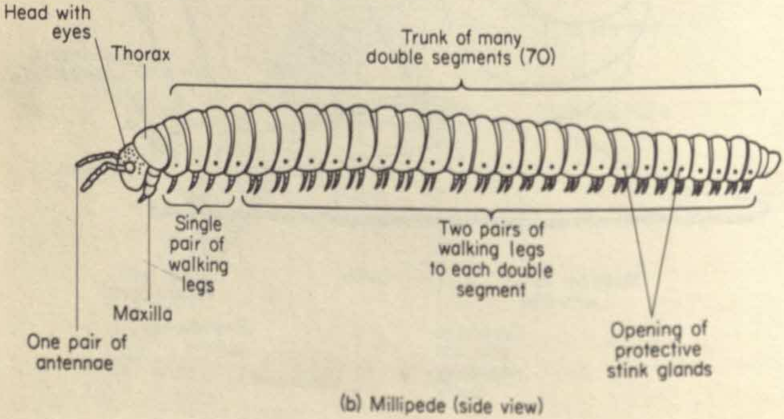
(i) *Class Crustacea*

These are mainly found in sea water and fresh water,whilst the woodlouse, *Armadillidium*, is terrestrial under stones and wood. Many marine crus-

fig 2.15 *examples of arthropods: (a) a crustacean, shrimp,* Pandalus *sp. and (b) a myriapod, millipede,* Julus *sp.*



(a) Shrimp (side view)


Head with eyes
Thorax
Trunk of many double segments (70)
Single pair of walking legs
Two pairs of walking legs to each double segment
Maxilla
One pair of antennae
Opening of protective stink glands

(b) Millipede (side view)

taceae are important *zooplankton*, similar to shrimps (Fig. 2.15a), and as *krill* are the food of baleen whales.

(ii) *Class Myriapoda*

This class includes centipedes and millipedes (Fig. 2.15b), all of which are found in or on soil. They have long segmented bodies and *numerous* legs.

(iii) *Class Arachnida*

These are terrestrial arthropoda with *four* pairs of legs, and include spiders (Fig. 2.16b), scorpions and ticks.

(iv) *Class Insecta*

These are distinguished by a body divided into a *head*, *thorax* and *abdomen*, with *three* pairs of legs connected to the thorax. They are mainly terrestrial, and some have two pairs of *wings*, whilst others are *wingless*. More than 50% of all animal species are insects. The adult Tse-tse fly is shown in Plate 2.1.

plate 2.1 *the adult Tse-tse fly,* Glossina *sp., showing its external structure (World Health Organisation)*

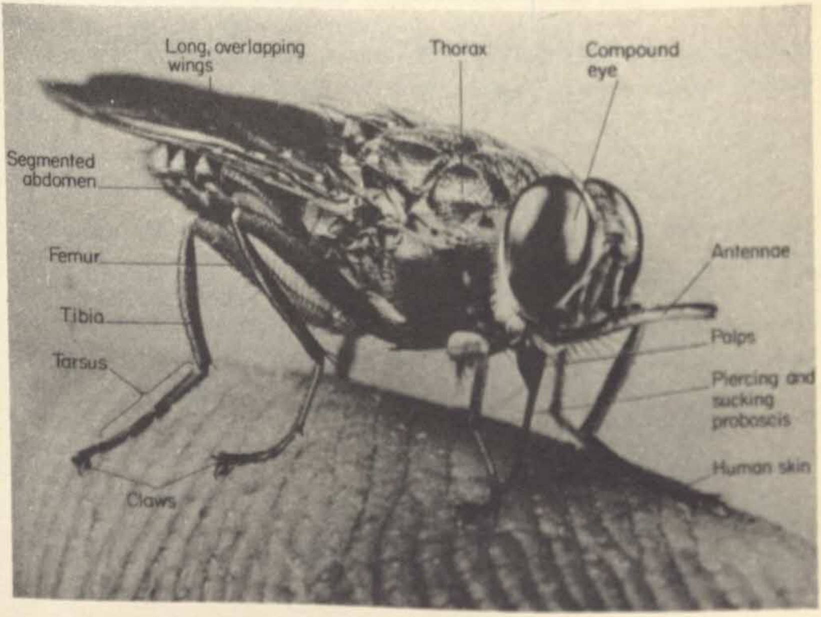
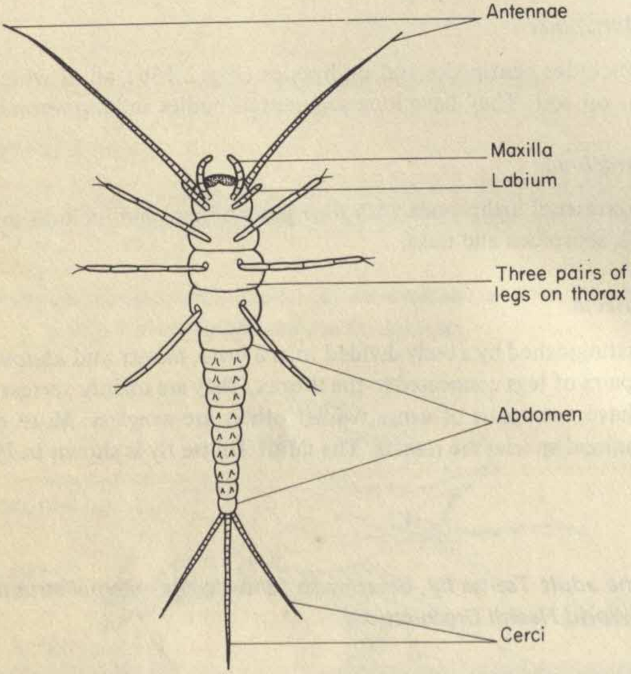
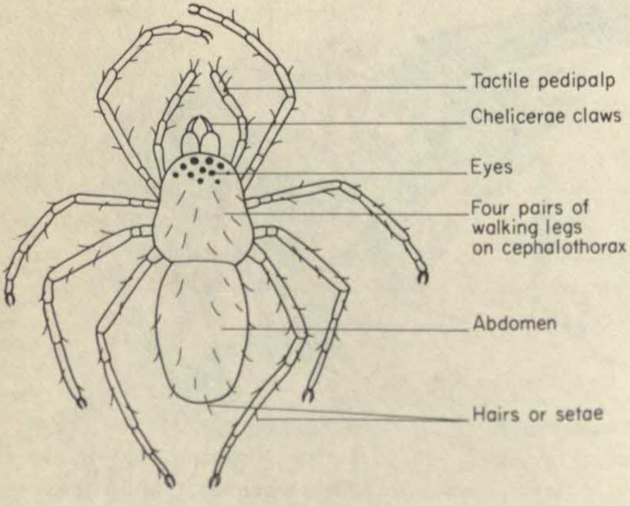


fig 2.16 *examples of arthropods: (a) a wingless insect, silverfish,* Lepisma *sp. and (b) an arachnid, spider,* Epeira *sp.*



(a) Silverfish (ventral view)



(b) Spider (dorsal view)

(1) Wingless insects

These include silverfish (Fig. 2.16a), a pest in dark cupboards.

(2) Winged insects

Winged insects showing *incomplete* metamorphosis (Section 15.10) include cockroaches, termites, locusts, lice and bedbugs.

Some winged insects show *complete* metamorphosis with a caterpillar-type larva and pupa. They may have only one pair of wings, the second pair being reduced to balancing *halteres* as in the housefly, or they may be wingless as in the human flea. Examples include beetles, mosquitoes, ants, bees, butterflies, moths and wasps.

(i) Phylum Echinodermata, the 'spiny-skinned' animals

This phylum consists entirely of marine animals which have a tough thick skin set with *spines* and *plates*. The adult body may have five rays and the mouth is on the ventral surface.

The phylum includes starfish, *Asterias* (Fig. 2.17), sea urchins, feather stars, brittle stars and sea cucumbers.

(j) Phylum Chordata

This phylum comprises about 6% of all animal species. Members of this phylum show the following at *some* time during their life history. They may possess a dorsal nerve cord, and a notochord beneath the nerve cord. The notochord acts as a skeleton support.

The important chordates for our studies are members of the subphylum *vertebrata* which all possess a *vertebral column* and *cranium* (see Section 14.3).

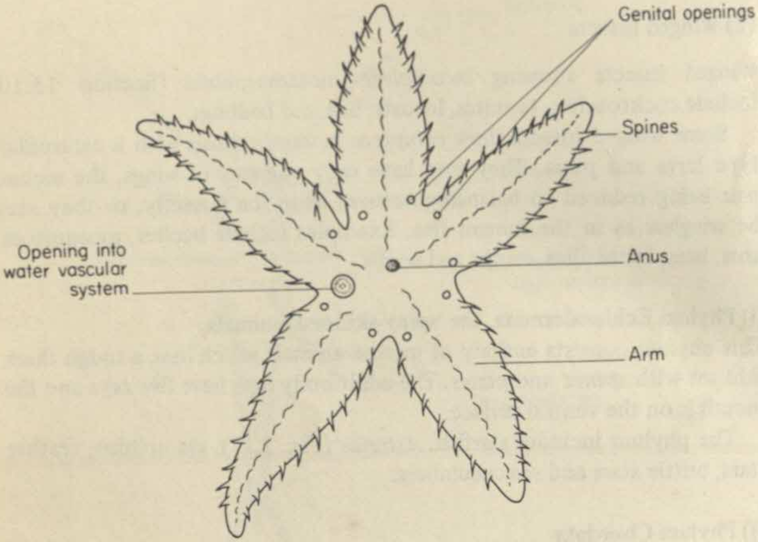
(i) *Class Pisces, the fish*

These are aquatic vertebrates with *fins* and *scales* covering the body, and they have *gills*. *Cartilaginous* fish (dogfish and ray) have broad pectoral and pelvic fins (Fig. 2.18a). *Bony fish* (herring and three-spined stickleback) have delicate fan-like fins (Fig. 2.18b). The skin scales of bony fish are *bony* in contrast to cartilaginous fish skin which is rough and spiny (see Section 14.9).

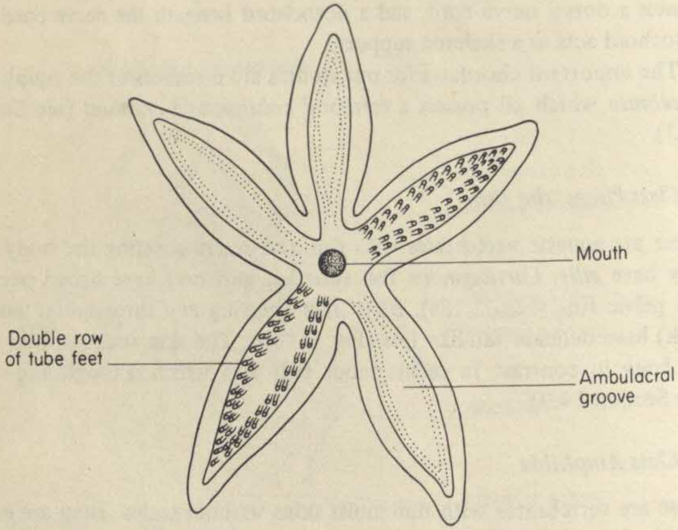
(ii) *Class Amphibia*

These are vertebrates with thin moist skins without scales. They are *partly* aquatic, being born in water, and are later terrestrial, living in damp places. Frogs (Fig. 2.19) and newts are *tailless* when adult, whilst newts have *tails* when adult.

fig 2.17 *external features of an echinoderm, the starfish,* Asterias *sp.*

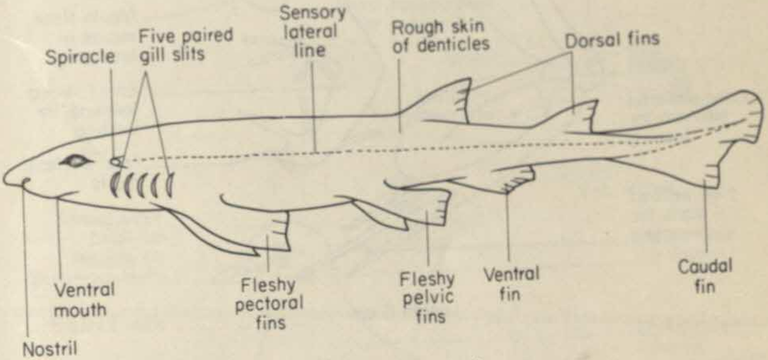


(a) Dorsal view

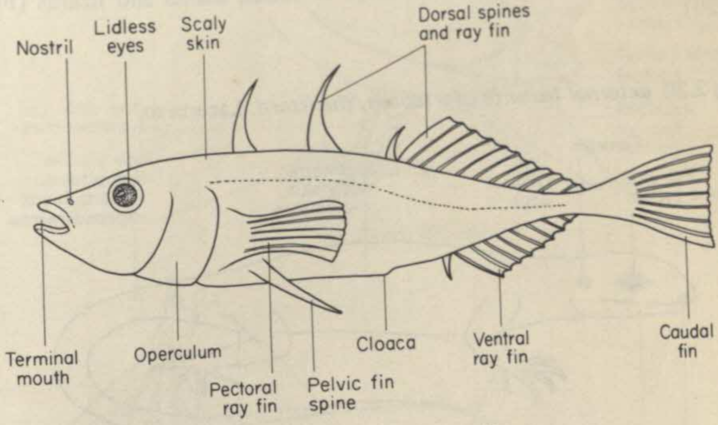


(b) Ventral view

fig 2.18 ***external features of (a) a cartilaginous fish, the dogfish,*** Scyliorhinus ***sp. and (b) a bony fish, the three-spined stickleback,*** Gasterosteus aculeatus

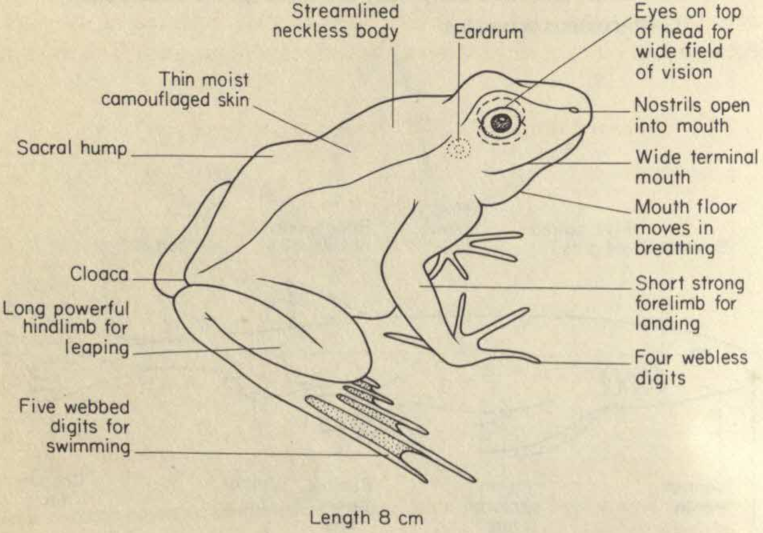


(a) Dogfish (60 cm)



(b) Three–spined stickleback (6 cm)

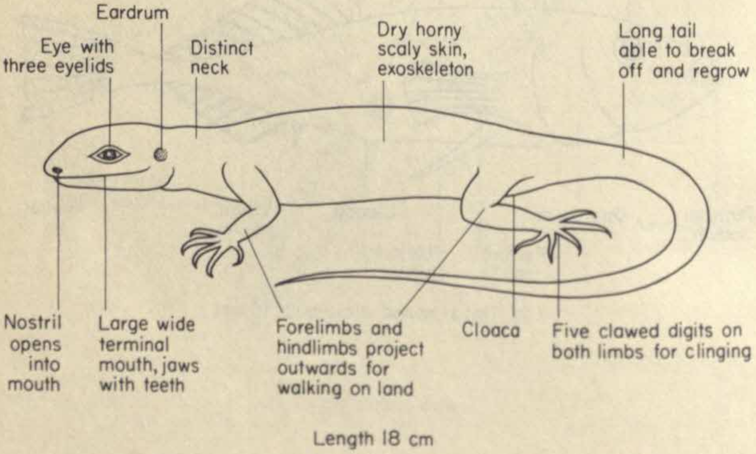
fig 2.19 *external features of a frog,* Rana *sp.*


Streamlined neckless body
Eardrum
Eyes on top of head for wide field of vision
Thin moist camouflaged skin
Nostrils open into mouth
Sacral hump
Wide terminal mouth
Mouth floor moves in breathing
Cloaca
Short strong forelimb for landing
Long powerful hindlimb for leaping
Four webless digits
Five webbed digits for swimming
Length 8 cm

(iii) *Class Reptilia*

These are terrestrial vertebrates with dry *scaly* skins. They lay eggs on land in leathery shells. The class includes tortoises, snakes and lizards (Fig. 2.20).

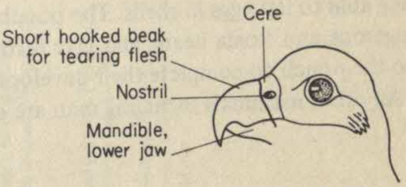
fig 2.20 *external features of a reptile, the lizard,* Lacerta *sp.*


Eardrum
Eye with three eyelids
Distinct neck
Dry horny scaly skin, exoskeleton
Long tail able to break off and regrow
Nostril opens into mouth
Large wide terminal mouth, jaws with teeth
Forelimbs and hindlimbs project outwards for walking on land
Cloaca
Five clawed digits on both limbs for clinging
Length 18 cm

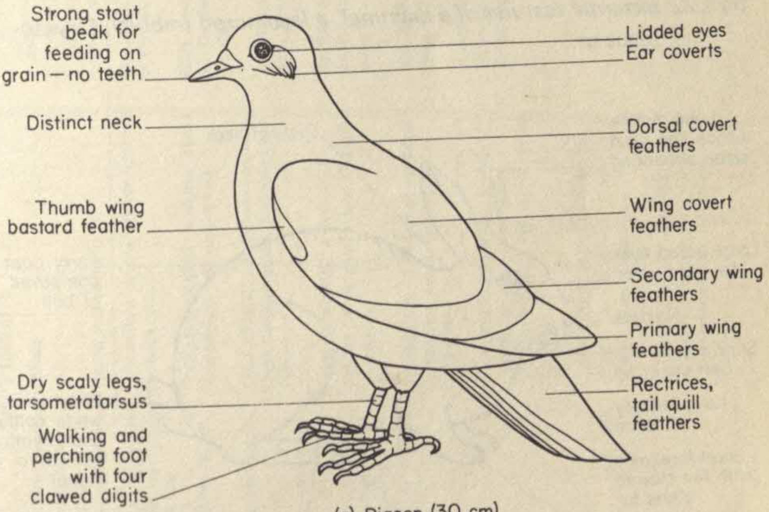
(iv) *Class Aves*

The birds are warm-blooded, have bodies covered in *feathers* and have *scales* on their legs (Fig. 2.21). The forelimbs are modified as *wings* (see Section 14.11). Beaks are hard horny structures without teeth. The majority

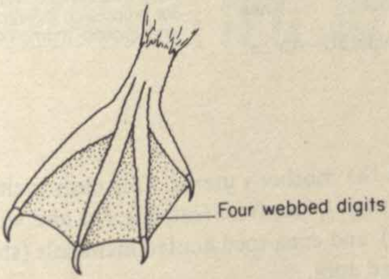
fig 2.21 ***external features of a bird, the pigeon,*** Columba ***sp.***



(b) Bird of prey, e.g. falcon


Strong stout beak for feeding on grain — no teeth
Distinct neck
Thumb wing bastard feather
Dry scaly legs, tarsometatarsus
Walking and perching foot with four clawed digits
Lidded eyes
Ear coverts
Dorsal covert feathers
Wing covert feathers
Secondary wing feathers
Primary wing feathers
Rectrices, tail quill feathers

(a) Pigeon (30 cm)



(c) Swimming bird, e.g. shag

of birds can fly, but the *flightless* birds include the penguin, ostrich and kiwi. All lay eggs in hard protective shells.

(v) *Class Mammalia*

Mammals are warm-blooded, have bodies covered with *hair* and have mammary glands which produce *milk* (Fig. 2.22). All have *external* ears.

The duck-billed platypus is a *monotreme* mammal, distinguished by being able to lay eggs in shells. The pouched or *marsupial* mammals include kangaroos and koala bears, and give birth to *immature* young which climb into the pouch to complete their development.

All other mammals including man are *eutherian* mammals, meaning that the young develop more fully in the mother's uterus. This class includes the following *orders;* Insectivora (mole), Carnivora (cat, dog, fox and wolf), odd-toed hoofed mammals (horse), and even-toed hoofed mammals (sheep and goat). Primates include man and apes.

fig 2.22 ***external features of a mammal, a lagomorph (rabbit),*** Oryctolagus *sp.*

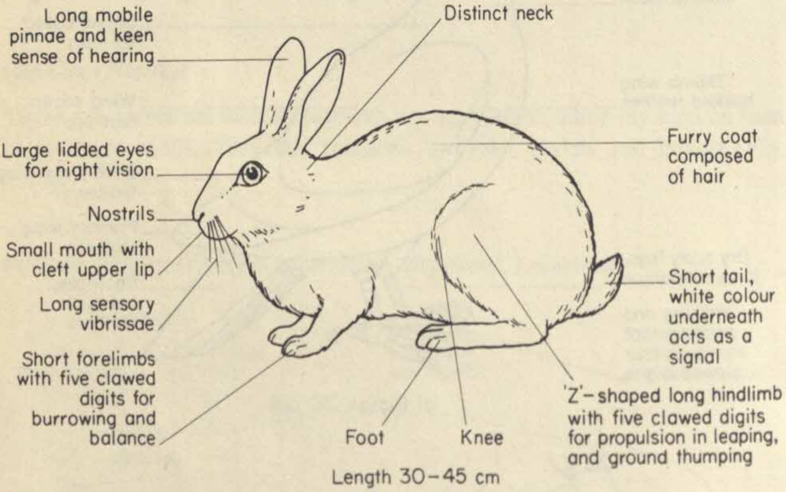

Long mobile pinnae and keen sense of hearing
Large lidded eyes for night vision
Nostrils
Small mouth with cleft upper lip
Long sensory vibrissae
Short forelimbs with five clawed digits for burrowing and balance
Distinct neck
Furry coat composed of hair
Short tail, white colour underneath acts as a signal
'Z'-shaped long hindlimb with five clawed digits for propulsion in leaping, and ground thumping
Foot
Knee
Length 30–45 cm

Table 2.3 is an outline tabular survey of the animal kingdom.

Table 2.3 *tabular survey – animals*

INVERTEBRATES:		VERTEBRATES:
1 Animals without vertebral columns 2 Variable body form 3 No gill slits 4 If there is a central nervous system, it is *ventral*		1 Animals with vertebral columns 2 Body of head, trunk and tail 3 Gill slits at some time 4 *Dorsal* nervous system
PROTOZOA A phylum of one-celled organisms of microscopic size. *Amoeba* – moves by pseudopodia. *Euglena* – moves by a flagellum. *Paramecium* – moves by cilia. SPONGES A phylum of freshwater/marine animals. The single body cavity has *many* inlets but only *one* outlet.	Multicellular animals with one main *inlet* to body cavity: COELENTERATES A phylum. Hydra and jelly-fish with stinging cells. FLATWORMS A phylum of animals with flattened bodies. Tapeworms and liverfluke. ROUNDWORMS A phylum of cylindrical elongated worms. Dog and cat worms. ANNELIDS A phylum of segmented cylindrical worms. Earthworm and lugworm. ARTHROPODS A large phylum of insects, spiders and centipedes. Segmented bodies with paired jointed legs. MOLLUSCS A phylum of animals with a distinct head and protective shell. Oyster and octopus. ECHINODERMS A phylum of animals with spiny skins, and globe or star-shaped bodies. Starfish and sea urchin.	The *phylum* CHORDATA is made up of the following *classes*: FISH Scaly skins. Gills. Paired fins. (a) Dogfish – cartilaginous fish. (b) Cod – bony fish. AMPHIBIA Soft skins, gills in tadpoles, paired limbs. Newts and frogs. REPTILES Scaly skins, lungs, gill slits in embryo. Paired limbs in lizard. Vestigial limbs – snake. BIRDS Feathers and scaly legs. Forelimbs – wings. Gill slit in embryo. Hen and pigeon. MAMMALS Skin with glands and hair. Mammary gland secretes milk. Gill slit in embryo. Rabbit, dog, seal and man.

2.7 QUESTIONS

1 List the characteristics showing why the following living things belong to a certain group or phylum: tortoise, housefly, field mushroom, dandelion, snail, blackbird, starfish, earthworm.

2 Give the reasons in each case why the following animals belong to different classes: penguin, herring, seal, newt, snake.

3 Describe two features for each of the following groups of living things which distinguish them from the others: (a) ferns; (b) mosses; (c) fungi.

4 Name two animals in each case which have the following structural features: (a) feathers; (b) three pairs of legs; (c) tentacles; (d) five arms; (e) one foot; (f) chaetae; (g) vibrissae.

5 Name two plants in each case which have the following structural features: (a) mycelium; (b) thallus; (c) cones; (d) air bladders; (e) flowers; (f) axillary buds; (g) sporangium.

6 Draw a bar graph, histogram or pie diagram showing the numbers of plant species in different phyla from the following figures: Algae 20 000 species; Fungi 80 000; Bryophyta 25 000; Pteridiophyta 10000; Spermaphyta 300000.

7 Draw a bar graph, histogram or pie diagram showing the numbers of animal species in different phyla from the following figures: Protozoa 50 000 species; Coelenterates 9400; Flatworms 5500; Roundworms 10 000; Annelida 7000; Mollusca 45 000; Arthropoda 750 000; Echinoderms 5400; Chordates 51 000.

CHAPTER 3

NATURE OF LIVING ORGANISMS

3.1 CHARACTERISTICS OF LIVING ORGANISMS

Living organisms are characterised by the performance of certain *life processes* or *functions*, which distinguish them from *non-living* things. Non-living things may perform *one* or more of these processes, for example a crystal can *grow*, and a machine can *move*. It is only a living organism that can perform *all* of the following processes at some time in its *life*.

(i) *Movement* is of the *whole* body in *locomotion* or part of the body internally or externally in plants and animals (see Sections 11.10 and 14.5). *Transport* is a process of moving materials over short or long distances within the organism (Chapter 9).

(ii) *Irritability*, also called sensitivity and responsiveness, is the process of responding to changes in the surroundings or environment (Chapter 13).

(iii) *Feeding*, or *nutrition*, is the intake of energy and simple raw materials by plants and their synthesis into *food*. Food is used by plants and animals to construct and maintain life (Chapters 6, 7 and 8).

(vi) *Respiration* is the process of releasing *energy* from food, for the performance of life processes (Chapter 10).

(v) *Excretion* is the removal of waste products from chemical reactions which have occurred in the organism (Sections 12.4 and 12.6).

(vi) *Growth* is generally an increase in size of an organism (Section 11.2).

(vii) *Reproduction* occurs at some time in an organism's life, and is a process of continuing life of the species by offspring (Chapter 15 and Section 16.5).

(a) Homeostasis

All the life processes occurring in the living organism must be performed in spite of *changes* in the surrounding environment and of different *demands* on the organism. *Homeostasis* is a *self-regulating* control which keeps the living organism functioning correctly (Section 12.1).

(b) Division of labour

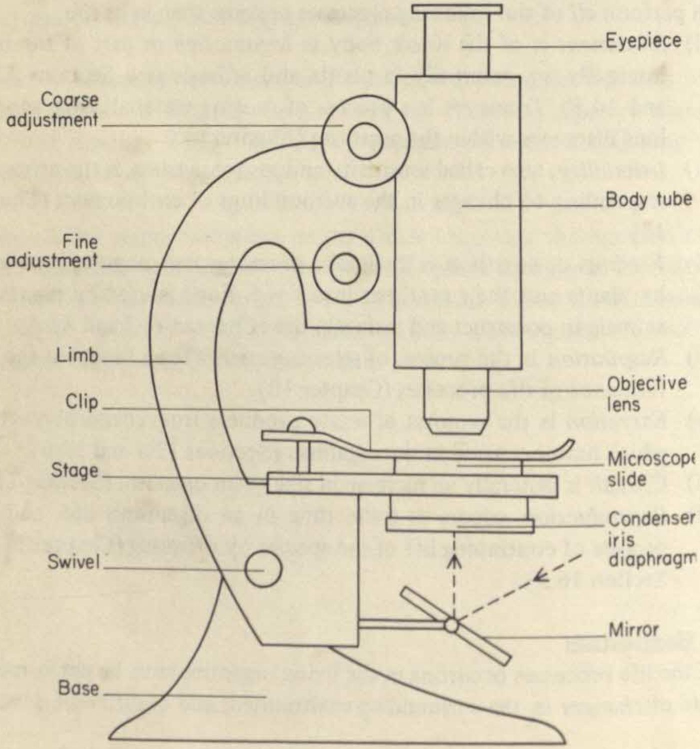
The different life processes involve special functions which are carried out in a particular *part* of an organism specially set aside for this purpose.

3.2 MICROSCOPES

Magnifying lenses are biconvex lenses that are thickest in the middle. The human eye has such a lens (Section 13.4). Magnifying lenses can magnify an *object* to produce an *image* up to 20 times the object size.

Compound or light *microscopes* (Fig. 3.1) are composed of *two* convex lenses, the *eye* lens (eyepiece) magnifying up to 10 or 20 times (× 10 or ×20), and the *object* lens (objective) magnifying within the following ranges of ×4, ×10, ×20 or ×40.

fig 3.1 *parts of a light (optical) microscope*



The combination of two lenses gives a greater *total* magnification: a ×10 eyepiece with a ×40 objective gives a total magnification of 10 × 40 or 400 times. The most powerful magnification obtainable with a light microscope is ×1000. This is achieved with a ×100 oil immersion objective. A drop of cedarwood oil is placed between the objective and the microscope slide when using this powerful lens.

Light microscopes can be used to provide photographs called *photomicrographs*; alternatively, the image can be projected onto a screen by a *microprojector*.

The *electron microscope* (Plate 3.1) makes magnification possible up to 500 000 times, by using an electron beam instead of a light beam. Photographs are taken called *electron micrographs*; alternatively, the image can be viewed on a fluorescent *screen*.

Experiment 3.1 *using a microscope*

Procedure

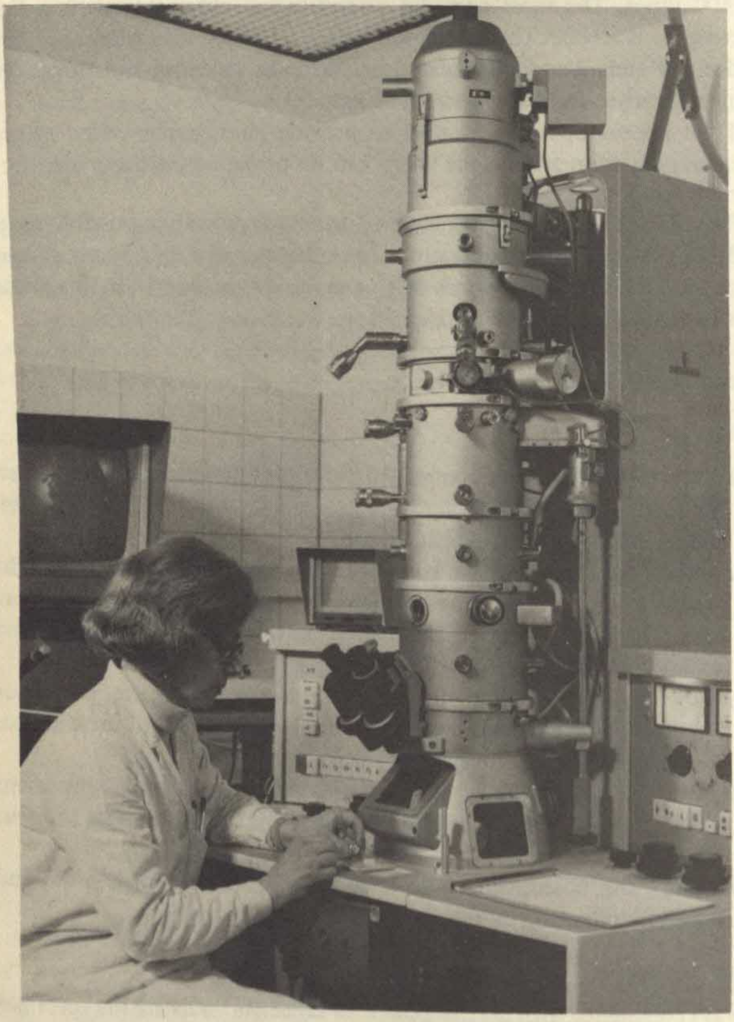
(i) Identify the following components: eyepiece, objective, coarse adjustment, fine adjustment, microscope stage and clips, condenser, illuminating mirror or built-in light source.
(ii) Reflect light from a table lamp onto the mirror and concentrate light onto the microscope slide held by clips on the stage. DO NOT use direct sunlight. Alternatively, switch on the built-in light source and adjust illumination by the diaphragm disc.
(iii) Turn the nosepiece to position the ×4 *low-power* objective. *With your eye level with the stage*, rack down the objective by the coarse adjustment until it *almost* touches the microscope slide.
(iv) With your eye at the eyepiece, *slowly* rack up the coarse adjustment until the specimen comes into view. Use the fine adjustment to *focus* the image accurately.
(v) Change the objective over to medium ×10 or high-power ×40, and adjust illumination by the diaphragm to obtain more light.

Observations

Always commence with the low-power ×4 objective, to *locate* the specimen and any particular *region*. Then make a detailed examination with the high-power objective. Clean optical surfaces with soft lens tissue damped with ethanol or propanol.

3.3 THE CELL THEORY

Following the development of the light microscope by Robert Hooke (1635–1703) and Antonie van Leeuwenhoek (1635–1705), Theodor plate 3.1 *the electron microscope (Bayer Ltd)*



Schwann (1810-1882), an anatomist, in 1839 put forward the theory that all animals and plants are composed of units of construction called *cells.* Later Rudolf Virchow (1821-1902), a pathologist, added that new cells form by *division* of existing cells, and this is responsible for *growth* and *reproduction* (Section 11.3).

There are some important exceptions to this theory. Many organisms are composed of *one* cell or are *unicellular*, for example Protozoa, bacteria and certain algae and fungi. Most plants and animals are composed of *many* cells (or are *multicellular*), in accordance with the theory.

Acellular or non-cellular organisms are not divided into separate cells. Certain algae and fungi do not show individual cell structures, and they are called *coenocytes*. Certain animals and parts of animals, for example skeletal muscle, do not show individual cells, and are called a *syncytium*.

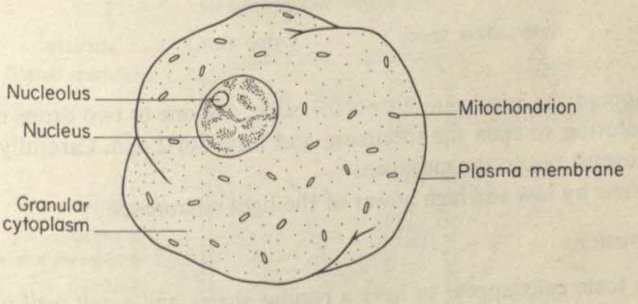
Dead or non-living cells can form part of a living organism. For example, the outer surface of human skin consists of dead scale cells, and hair is a non-living cellular material. Flowering plants have dead cells forming *wood* and *cork*, and also linen and cotton *fibres*.

Experiment 3.2 *looking at cells*

Procedure A – animal cells (Fig. 3.2)

(i) Sterilise a spoon *handle* by dipping in antiseptic solution. Scrape it gently inside the cheek of the mouth.
(ii) Transfer the cloudy substance onto a clean microscope slide, and place it close to the reading lamp to *dry*.

fig 3.2 *an example of an animal cell – the human cheek epithelium cell*



(iii) Add one or two drops of methylene blue solution; this is a microscope *stain* reagent. Leave on the dry smear for 2 min. Gently rinse with clean water and dab off excess water with blotting paper.
(iv) Add one drop of glycerine (propanetriol) to the stained specimen. Carefully lower a square coverslip by one edge, guiding it into position with a needle.
(v) View the stained preparation with the low and high power of the light microscope.

Observations

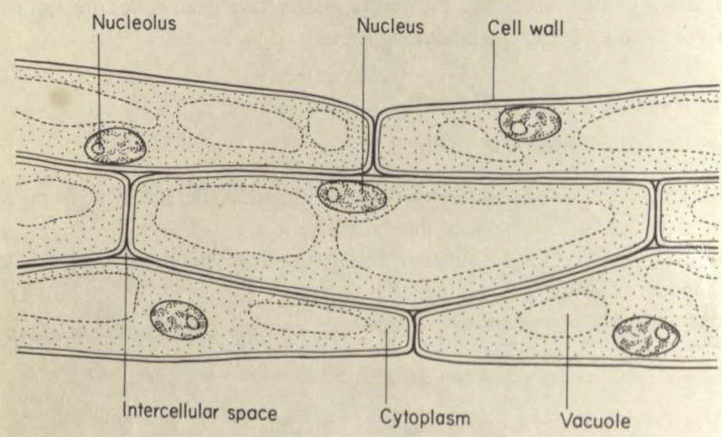
Note the irregularly shaped cells and their central *nucleus*.

A large number of dark circles on the slide can be due to *air bubbles* and are frequently mistaken by beginners as cells.

Procedure B – plant cells (Fig. 3.3)

(i) Strip off the thin translucent material (tissue) from the inner surface of a fleshy onion scale. Place in a dish of water and cut a small portion with scissors. Transfer to a clean microscope slide with a camel-hair brush or needle.

fig 3.3 *an example of plant cells – the onion,* Allium *sp., leaf scale cells*



(ii) Spread the specimen out on the slide, add one or two drops of iodine solution to stain the specimen, and leave for 2 min. Carefully lower a coverslip onto the specimen.
(iii) View by low and high power of the light microscope.

Observations

Onion scale cells appear to have a regular shape, and a *cell wall* is clearly visible in addition to the nucleus. In contrast to the human cheek lining cells, the plant cells are firmly *bound* together.

3.4 CELL STRUCTURE

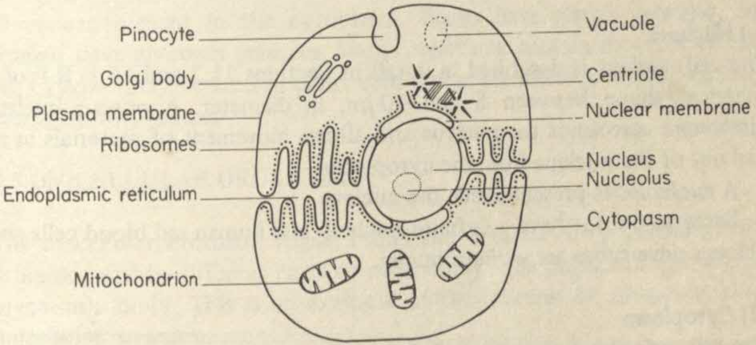
Knowledge of the fine structure of cells has been obtained mainly by means of the electron microscope, which shows structures invisible to the light microscope. *Cytology* is the study of cells.

Cells vary in size from 3μm diameter for white blood cells up to 500μm diameter for the *Amoeba* organism. There is a *limit* in cell size regulated by the surface area/volume *ratio*. When this limit is reached, the cell divides.

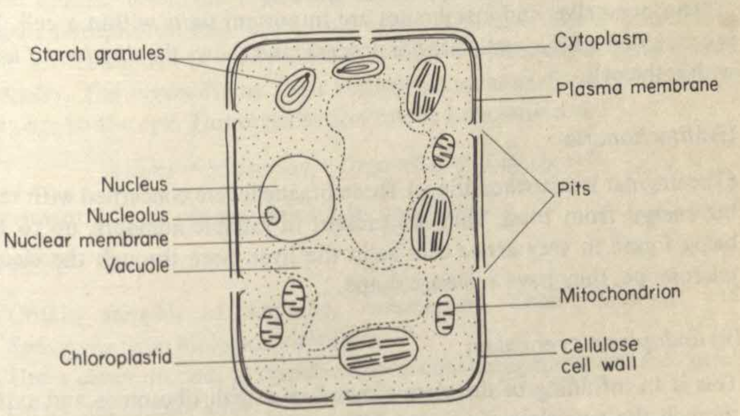
Protoplasm is the name given to the living substance that composes a cell. It consists of three main parts: the *plasma membrane*, the *cytoplasm* and a *nucleus*. Plant cells have a rigid *cell wall* enclosing the plasma membrane.

A cell can therefore be defined as a mass of protoplasm bounded by a plasma membrane in animals, and includes a surrounding cell wall in plants. Fig. 3.4 shows generalised plant and animal cells.

fig 3.4 ***generalised structures of (a) an animal cell and (b) a plant cell to show the organelles***



(a) Generalised animal cell



(b) Generalised plant cell

(a) Cell wall

Bacteria and plants have cell walls. The bacteria cell wall is of protein; certain fungi have cell walls of chitin; whilst most plants have cell walls composed of *cellulose*.

Cellulose walls are *permeable*, and give *strength* and *protection*. Some cells are given additional strength by being thickened with a woody material called *lignin*.

(b) Plasma membrane

This is the cell membrane or the outermost layer surrounding the cytoplasm. It is very thin and *flexible*, 10mm or one-hundredth of a micrometre in thickness, and composed of fatty lipid material and protein, as a *lipoprotein* substance.

The plasma membrane is selectively permeable or *semipermeable*, and is a *sensitive* region concerned with receiving *stimuli*. In plant cells, the membrane is close up against the cell wall.

(c) Nucleus

The cell nucleus is described in detail in Sections 11.2 and 16.1. It is of a spherical shape between 5 and 10 μm in diameter. A *porous* nuclear *membrane* surrounds the nucleus and allows movement of materials in to and out of the nucleus from the cytoplasm.

A *nucleolus* is present inside the nucleus.

Bacteria do not have a definite nucleus, and human red blood cells and phloem sieve tubes are *without* nuclei.

(d) Cytoplasm

The cell cytoplasm contains a *fluid*, certain *membranes*, and *organelles* or cytoplasmic structures with special functions.

The organelles and membranes are important *units* within a cell. Each is concerned with a particular *life process*, and shows the *division of labour* within the cell.

(i) *Mitochondria*

(The singular is mitochondrion.) These organelles are concerned with releasing *energy* from food. They are present in variable numbers, up to 1000 being found in very *active* cells as in the liver. Seen through the electron microscope, they have a sausage shape.

(ii) *Endoplasmic reticulum*

This is an infolding of the plasma membrane with ribosomes and extends through the cytoplasm from the cell membrane to the nuclear membrane. Its function is concerned with enzymes, chemical activity, protein manufacture and transport.

(iii) *Chloroplasts*

These are the organelles present in *green* plants. They are egg- or disc-shaped between 5 and 10 μm in diameter. They are the regions of food manufacture by photosynthesis (Section 6.2).

(iv) *Vacuoles*

Vacuoles are seen in plant cells as clear fluid-filled spaces lined by the plasma membrane, and can occupy up to 80% of a cell volume. They function to maintain turgidity and may contain soluble food and excretory wastes.

(v) *Granules and droplets*

These are present in the cytoplasm. Plants have starch granules, and animals have glycogen granules. Many organisms contain droplets of lipid oil. Crystals may be seen in plant cells; these are reserves of food or insoluble excretory wastes.

3.5 UNICELLULAR ORGANISMS

The unicellular Protozoa, Algae, Fungi and Bacteria carry out *all* the life processes within different parts or organelles of the single cell forming the organism's body. This is an example of the *division of labour* within a unicellular organism.

Unicellular organisms show the following levels of *organisation*. Starting at the *atomic* level, the organisms are composed of carbon, hydrogen, oxygen, phosphorus, sulphur and nitrogen chemical elements (CHOPSN). These are combined in many different ways to form organic compound *molecules*. The *organelles* by their various activities perform life processes giving *life* to the *cell*. This organisation can be summarised as

Atoms → Molecules → Organelles → A single cell

Experiment 3.3 *to observe unicellular organisms*

Procedure

(i) Obtain samples of *Amoeba*, *Paramecium*, *Chlamydomonas* and *Spirogyra* from biological suppliers.
(ii) Use a clean dropper to transfer a drop containing the specimen onto a *cavity* microscope slide.
(iii) Observe the specimen through low and high power of a light microscope.
(iv) Fast-moving specimens such as *Paramecium* and *Chlamydomonas* can be restrained by adding a drop or two of *clear* wallpaper paste (Polycell).

Observations

By contrast to the cells examined previously in Experiment 3.2, we see that unicellular organisms must perform *all* the life processes within one cell.

3.6 MULTICELLULAR ORGANISMS AND TISSUES

Most living organisms are multicellular, having developed from a *single* fertilised egg cell or zygote and having formed groups or *tissues* composed of cells similar in structure and function. The study of tissues is called *histology*.

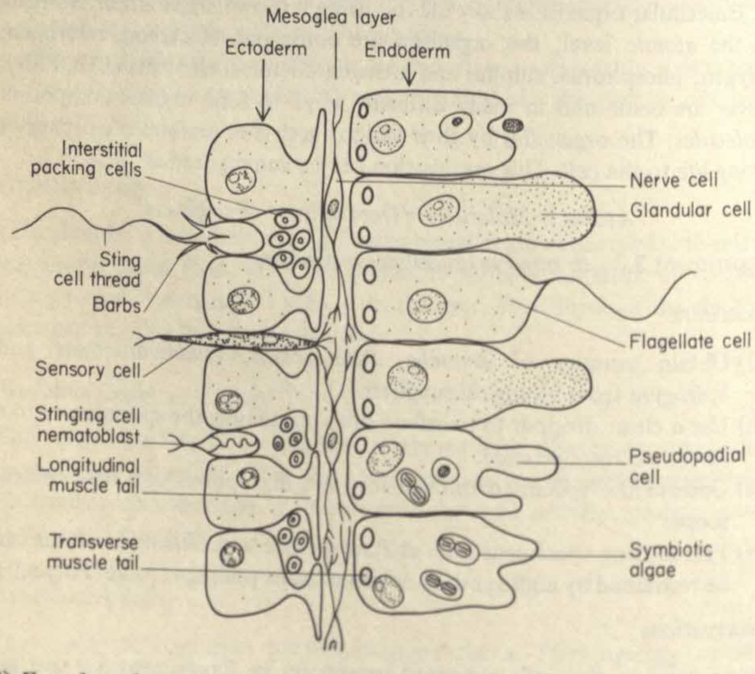
In multicellular organisms, the cells are *bound* together. Plants have their cells cemented together by *intercellular* gum-like materials. Animal cells are bound together by different intercellular materials outside the plasma membrane. Collagen is one such type of material.

Intercellular spaces are mainly air-filled in plants, and contain *tissue fluid* in animals.

(a) Hydra

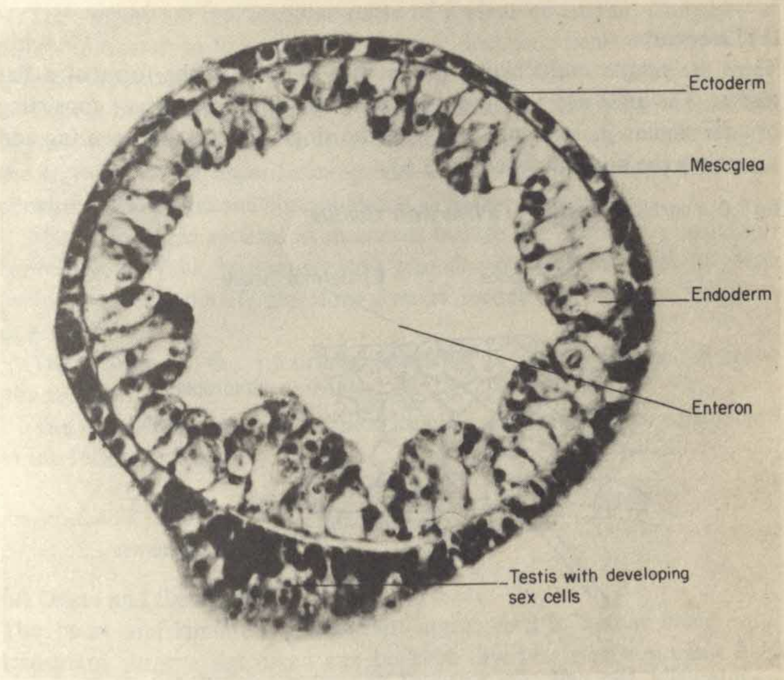
This multicellular organism has its body wall cells arranged in *two* main *layers*, the outer *ectoderm* layer and the inner *endoderm* layer (Fig. 3.5 and Plate 3.2).

fig 3.5 *a transverse section through the body wall of a* Hydra *sp.*



(i) *Ectoderm layer*

This is composed of cells with different structure and function. *Stinging cells* are grouped together on the tentacles to paralyse the *prey*. *Sensory* plate 3.2 *transverse section through a* Hydra *sp. body wall showing the testis (Griffin Biological Laboratories)*



cells detect touch stimuli, and help to capture the prey. *Musculo-epithelial* cells are partly protective and contractile. Their contraction and relaxation cause tentacle movement and move the food into the *Hydra's* mouth.

(ii) *Mesoglea layer*

This contains a network of nerve cells, forming nerve *tissue*, which coordinates body movements in the organism.

(iii) *Endoderm layer*

This is composed of musculo-epithelial cells, and the following cells concerned with feeding: *pseudopodial*, *flagellate* and *glandular* cells, the activity of which results in the digestion and ingestion of food. Interstitial cells are packing cells filling the intercellular spaces.

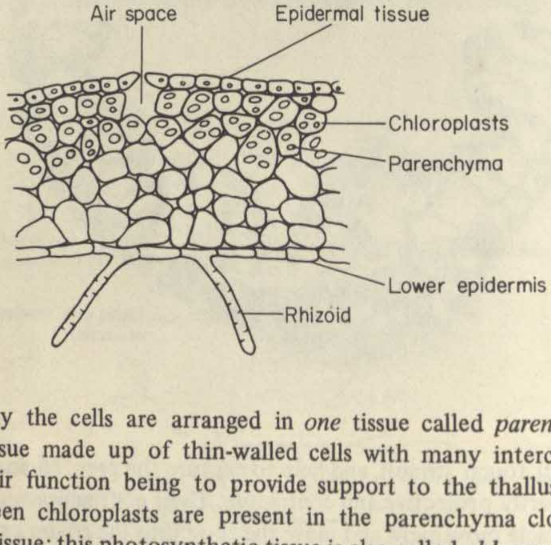
In the *Hydra*, the different cells in the different tissues *interact* with one another, each tissue being *interdependent* on the other. The tissues are *unable* to exist independently and no cell in *Hydra* has the ability to perform *all* life processes.

From time to time, special *sex cells* are formed in a part of the *Hydra* body, and these cells are called testes and ovaries or reproductive *organs*.

(b) Liverworts

These are simple multicellular plants with a body in the form of a flat *thallus*. The cells are arranged as tissues, the *epidermal tissue* consisting of cells similar in structure and with the single function of covering and protecting the body surface (Fig. 3.6).

fig 3.6 *a vertical section of a liverwort thallus*



Internally the cells are arranged in *one* tissue called *parenchyma* or packing tissue made up of thin-walled cells with many intercellular air spaces, their function being to provide support to the thallus by their turgor. Green chloroplasts are present in the parenchyma close to the epidermal tissue; this photosynthetic tissue is also called *chlorenchyma*.

Reproductive *organs* appear on the thallus to produce sex cells and a *spore*-producing organ (Section 15.5).

The liverwort and *Hydra* show an organisation that is more complex than that of unicellular organisms. It shows the *division of labour* between cells in *tissues*, and for short periods in reproductive organs. This can be summarised as follows for an organism:

Atoms → *Molecules* → *Organelles* → *Cells* → *Tissues*

3.7 MULTICELLULAR ORGANISMS AND ORGAN SYSTEMS

A human being commences life as a one-celled zygote which by repeated division produces an adult with between half-a-million million and one-million million cells. These cells become *differentiated* into *tissues*, but these are unable to function alone as in the simple multicellular organisms, and are combined with other tissues to form *organs*.

The organs are multicellular parts of a plant or animal, composed of *different* tissues, to form a structural unit, such as a heart or leaf, with a *specific* function.

Organs are unable to function alone in isolation. They *interdepend* and interact with other organs to form a complete *organ system*. For example, the stomach is one organ forming *part* of the *digestive system*, which also consists of intestines and certain glands as component organs.

The main organ systems in mammals include the digestive, circulatory, excretory, nervous, respiratory and reproductive systems, each of which performs one of the life functions given in Section 3.1, with the exception of growth.

The study of the processes occurring in organ systems is called *physiology*.

The *organisation* of complex multicellular organisms can be summarised in the following way:

Atoms → Molecules → Organelles → Cells → Tissues →
Organs → Organ systems

(a) Organ and tissue culture

The heart and kidney are important organs used in human-being organ transplant surgery. An organ can be kept alive in a sterile nutrient fluid maintained at a suitable pH, temperature and supply of oxygen. In a similar manner, a tissue culture is maintained for use in tissue transplanting.

3.8 MAMMAL TISSUES

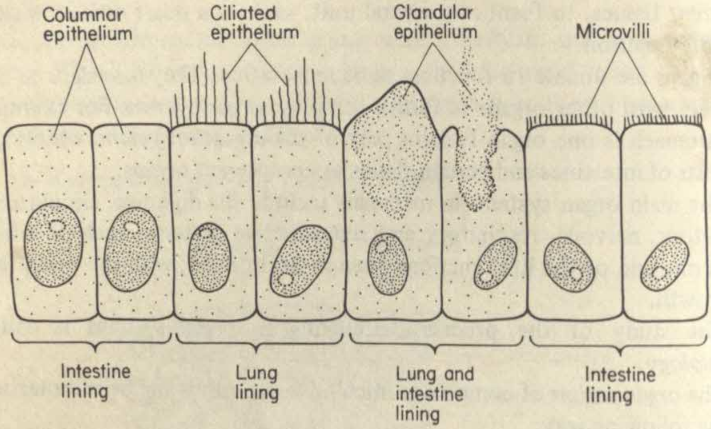
Mammal organs will be composed of two or more of the following different tissues. For example, a heart is composed of muscle, lining, nerve and blood tissues. Details of these tissues are given in later sections.

(a) Epithelial tissue

This tissue in the form of sheets of cells *covers* or *lines* internal and external surfaces of body organs and glands (Fig. 3.7).

Covering epithelia are found lining the mouth cavity as seen in Experiment 3.2, and as part of the skin (Section 12.9), intestine lining (Section 7.8), lining the trachea (Section 10.9) and blood vessels (Section 9.8). Covering epithelia function to *protect* inner tissues, and allow *passage* of substances through the epithelia.

Glandular epithelia secrete different substances: tears from tear glands (Section 13.4), sweat and fatty substances from skin glands (Section 12.9), fig 3.7 *different types of columnar epithelium and their location in a mammal*



and digestive enzymes and lubricating materials from the stomach and salivary glands (Section 7.7).

(b) Connective tissue

This tissue is in different forms and its function is to *support*, *enswathe* or *bind* other tissues.

Skeletal tissue includes *bone* and cartilage (Section 14.3). *Sheaths* are found around many organs, e.g. kidneys and muscles. *Tendons* and *ligaments* are used to connect muscles to bones, and bones to bones (Section 14.6).

(c) Blood and lymph

These are tissues that circulate between other tissues and organs and consist of *cells* and *fluid* (Section 9.6).

(d) Muscle tissue

This is *contractile* tissue able to contract and relax and is of three main kinds (Sections 14.5 and 14.6).

(e) Nerve tissue

This tissue is able to *receive* and *conduct* stimuli (Sections 13.3 and 13.10).

(f) Reproductive tissue

Sex cells or *gametes* form from reproductive tissue in the reproductive organs (Section 15.13).

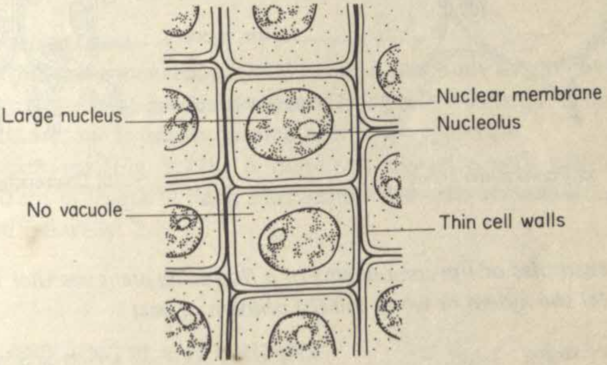
3.9 FLOWERING PLANT TISSUES

Flowering plants, due to their *sedentary* way of life and method of *nutrition* in making their own food, have a smaller range of tissues, and consequently fewer organs. The main organs are the leaf, stem, root, bud and flower.

(a) Meristem tissue

This tissue (Fig. 3.8) consists of cells which *divide* in regions at the root and shoot tip or in the *apical meristems* (Section 11.7). A *cambium* meristem is found inside the vascular tissue described below.

fig 3.8 *cells from the meristem of a flowering plant*



(b) Epidermal tissue

This resembles mammal epithelial tissue in having a *protective* function, and in *covering* the outer surface of the plant body. It is seen in the leaf epidermis (Section 6.4) and in the root and stem epidermis (Section 3.10), and in a tree trunk *bark*.

(c) Chlorenchyma

This is the photosynthetic tissue (Fig. 3.9b) containing chloroplast organelles seen in the leaf (Sections 3.6 and 6.4).

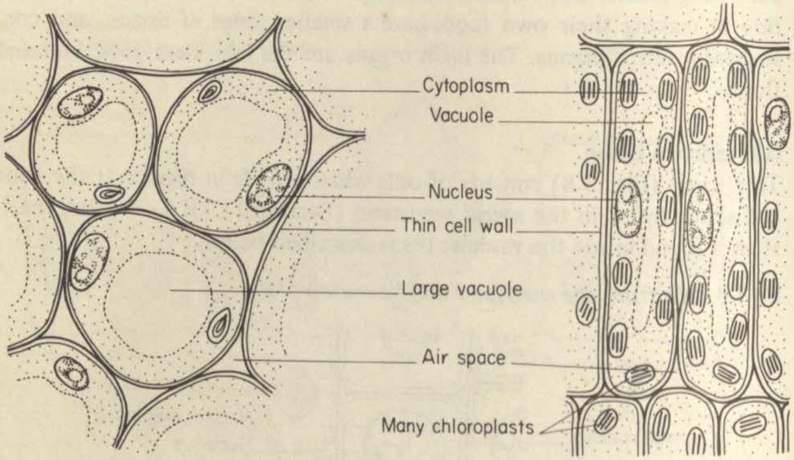
(d) Parenchyma

This is the packing cell tissue (Fig. 3.9a) with thin walls and numerous intercellular air spaces described in Section 3.6, and found in stems and roots (Section 3.10).

(e) Vascular tissue

This may be compared to the blood vessels of mammals as a tissue for *transporting* materials through the flowering plant.

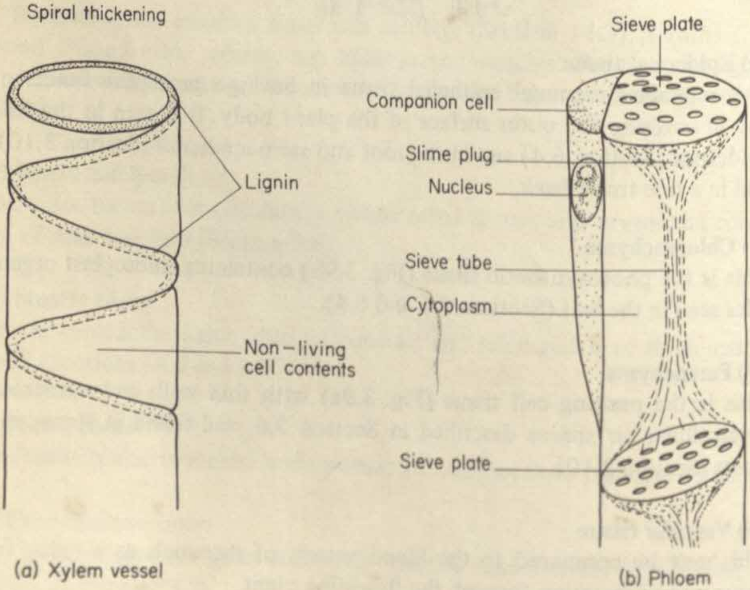
fig 3.9 *(a) parenchyma or packing tissue and (b) chlorenchyma or photosynthetic tissue from a flowering plant*



(a) Parenchyma tissue

(b) Chlorenchyma tissue

fig 3.10 *examples of the components of a flowering plant vascular tissue; (a) the xylem or wood and (b) phloem or bast*



(a) Xylem vessel

(b) Phloem sieve tube

Xylem tissue (Fig. 3.10b) consists of long non-living tubular vessels whose walls are thickened with woody *lignin*. The vessels are grouped together in vascular bundles and function to transport water and soluble substances from the root to the stem and leaf (Section 9.4).

Phloem tissue (Fig. 3.10a) is the other component of a vascular bundle. It consists of *living* cells called *sieve tubes*, which have perforated end walls called sieve *plates*. Associated with the sieve tubes are the smaller *companion cells*.

The function of the phloem is to transport food materials up and down the plant in the *translocation* system (Section 9.5).

The *cambium* separates the xylem from the phloem in a vascular bundle, and is responsible for secondary growth in woody stems and roots.

(f) Supporting tissue

This resembles the mammal skeletal tissue; it functions to provide support.

Collenchyma (Fig. 3.11a) consists of living cells thickened at the corners with cellulose, and is usually located near to the epidermis.

Sclerenchyma (Fig. 3.11b) is non-living elongated cells which can be up to 50 cm in length in linen *Flax* stems. The cells are non-living *fibres*, with lignified walls.

3.10 FLOWERING PLANT ORGANS

The *flowers* are the reproductive organs (Section 15.6). The *leaf* is the photosynthetic organ (Section 6.4). The leaf also functions in another process together with the stem and root in the *transpiration* system (Section 9.3). The root, stem and seed also function as part of *storage systems*.

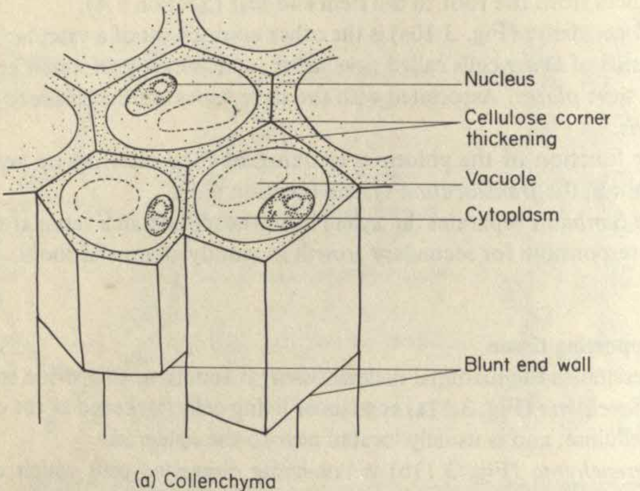
The two main organs, the root and stem, are described as follows in which it will be seen that many *different* tissues compose each organ.

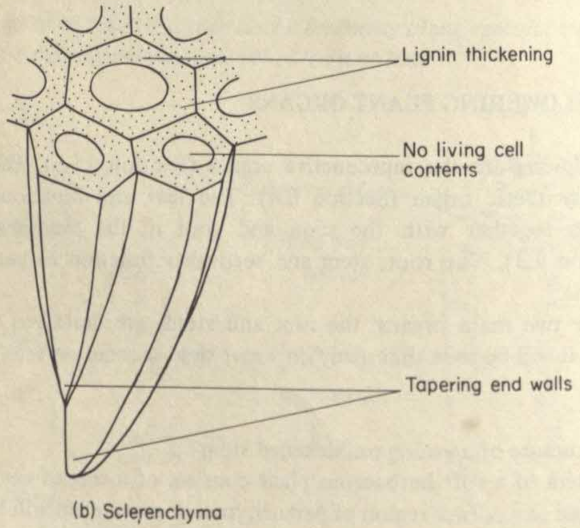
(a) Structure of a young unthickened stem

The stem of a soft herbaceous plant consists of a ring of vascular *bundles* arranged in a *cortex* region of parenchyma. A green stem will have chlorenchyma tissue beneath the epidermis layer. The central tissue of a stem consists of *pith* and is mainly parenchyma tissue.

Each vascular bundle has phloem towards the outside of the cambium, and xylem arranged inwardly. The soft tissue of the phloem may be protected by sclerenchyma fibres.

fig 3.11 *examples of a flowering plant strengthening tissue: (a) the collenchyma and (b) the sclerenchyma*





Collenchyma tissue is sometimes located beneath the epidermis in certain plants to provide strength and support.

The tissues in a flowering plant stem are shown in Plate 3.3 and Fig. 3.12.

plate 3.3 *a photomicrograph showing the structure of a maize,* Zea *sp. stem seen in transverse section (Griffin Biological Laboratories)*

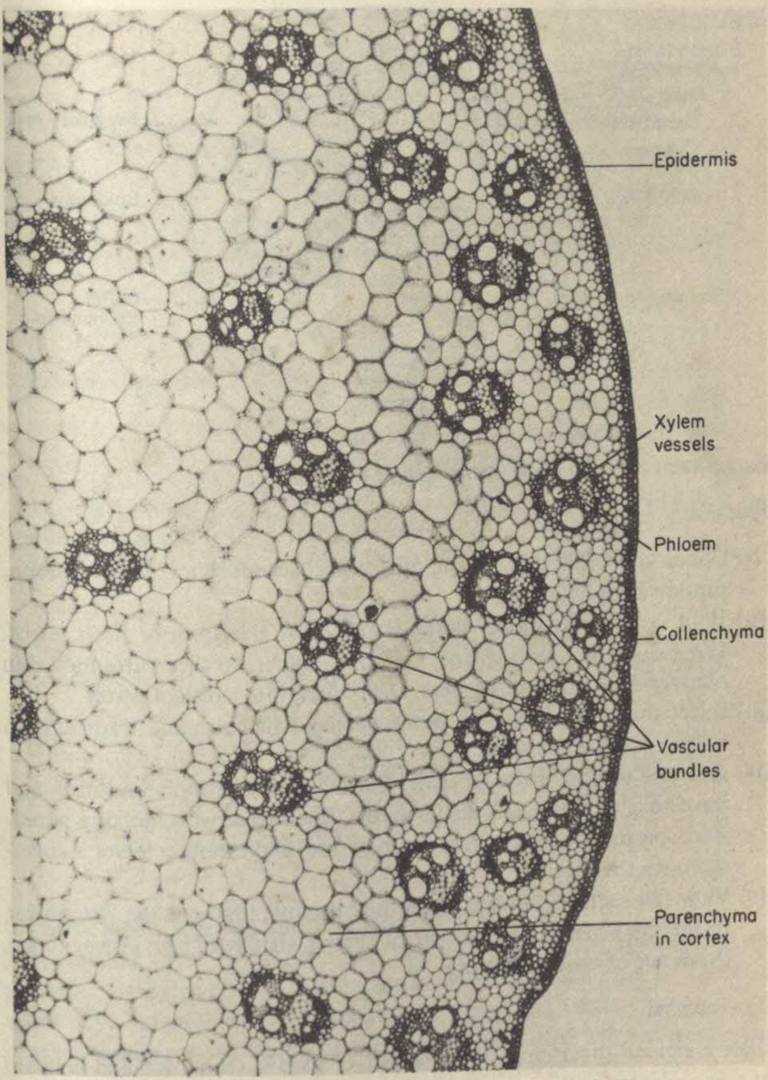
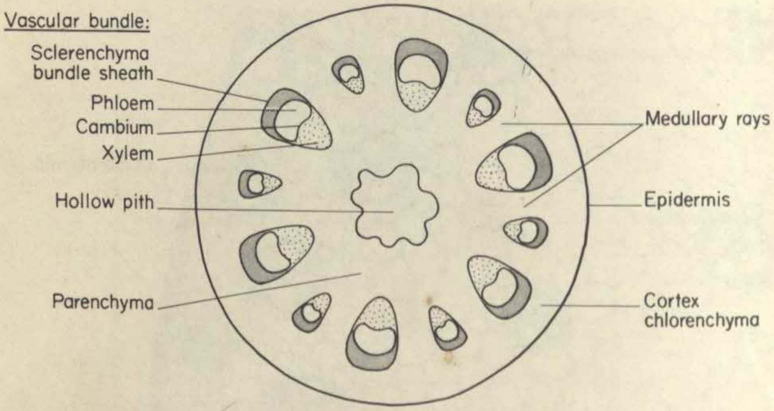


fig 3.12 *a general diagram showing the arrangement of the different tissues in a flowering plant stem. Transverse section of a buttercup,* Ranunculus *sp., stem*



Experiment 3.4 *to observe the tissues in a stem*

Procedure

(i) Obtain short lengths, 3–5 cm, of soft herbaceous stems, e.g. buttercup, sunflower or cucumber.
(ii) Hold the stem vertically between pieces of elder pith or fresh carrot. Use a sharp flat razor blade, held in a holder, to slice extremely thin *transverse* sections of the stem. Drop them into a dish of water.
(iii) Select the thinnest section using a camel-hair brush and transfer it to a clean microscope slide.
(iv) Add one or two drops of either Safranin stain or iodine solution and leave to stain for 2–3 min. Dab off the excess with blotting paper. Add one drop of propanetriol (glycerine) and carefully lower a cover-slip onto the section.
(v) View the section through a light microscope, first with the low power to see the *general arrangement* of tissues, then with high power to see the *detail* of tissue structure.

Observations

Draw a *general* diagram to show layout of tissues, then a detailed diagram of a *few* selected cells.

Table 3.1 summarises stem internal structure.

Table 3.1 *summary of stem internal structure*

Tissue	*Structure*	*Function*
Epidermis	1 Cuticle thick and waxy 2 Single layer of cells 3 Stomata and lenticel pores	1 Prevent water loss and waterproofing 2 Protect inner tissue 3 Exchange of gases and water vapour – *transpiration*
Cortex	1 Parenchyma (packing tissue) 2 Sometimes chloroplasts in outer region	1 Transport water, salts and gases across stem 2 Photosynthesis in green stems 3 Food storage in rhizomes
Strengthening tissue	1 Collenchyma – cellulose thickening 2 Sclerenchyma – lignin thickening	1 Provides support beneath epidermis 2 Protects soft tissue of phloem
Vascular bundles: several in a ring or scattered	1 Outermost phloem of sieve tubes 2 Inner xylem of vessels 3 Cambium layer between the above	1 Translocation of organic food materials 2 Transpiration of water and salts 3 Formation of new phloem and xylem tissues
Pith	1 Parenchyma (packing tissue)	1 Limited support 2 May be hollow empty space

(b) Structure of a young unthickened root

The vascular tissue is arranged centrally in a *stele*. The xylem tissue resembles a star shape, with phloem tissue in between the arms of xylem. A single layer of *endodermis*, resembling an epidermal tissue, surrounds the central vascular tissue. Much of the root consists of a wide cortex region of parenchyma cells which may have starch granules as a food reserve.

The root epidermis is also called the *piliferous* layer, and many of the cells are modified into *root hairs*.

The tissues in a root are shown in Plate 3.4. and Fig. 3.13

plate 3.4 *a photomicrograph showing the structure of a maize,* Zea *sp. root seen in transverse section (Griffin Biological Laboratories)*

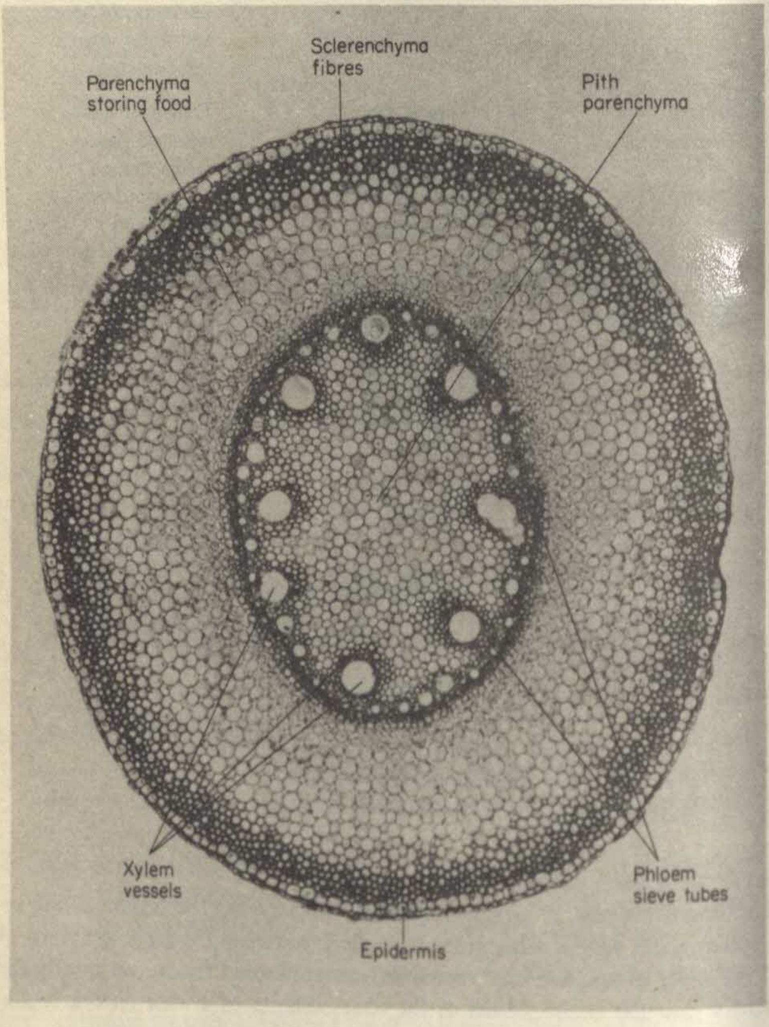
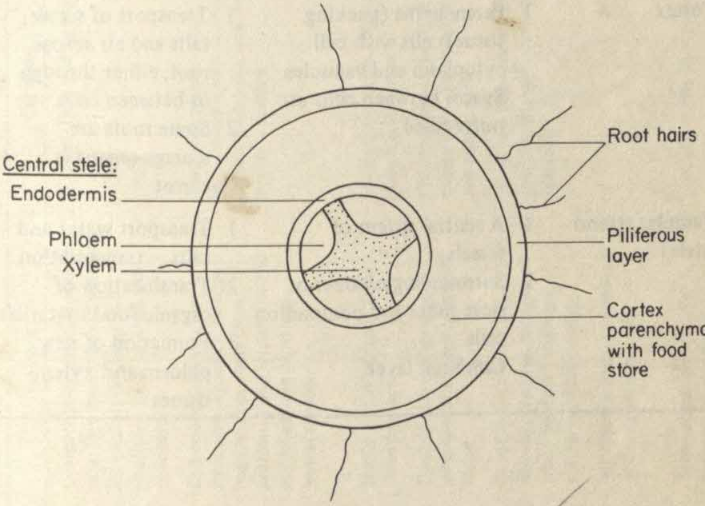


fig 3.13 *a general diagram of a buttercup,* Ranunculus *sp., root, in transverse section*



Experiment 3.5 *to observe the structure of a young unthickened root*

Procedure

(i) Obtain short lengths, 3–5 cm, of fresh broad bean and buttercup roots.
(ii) Proceed as in Experiment 3.4 to cut *transverse* sections, and mount and stain.

Observations

Draw a *general* diagram to show distribution of the different tissues, and then draw a *detailed* diagram of a few selected cells, particularly the root hairs.

Table 3.2 summarises root internal structure. Table 3.3 compares the differences between plants and animals.

Table 3.2 *summary of root internal structure*

Tissue	*Structure*	*Function*
Epidermis (piliferous layer)	1 No cuticle 2 Many *unicellular* root hairs	1 Absorption of water, salts and soil air 2 Protection of inner tissue
Cortex	1 Parenchyma (packing tissue) cells with cell cytoplasm and vacuoles 2 Spaces between cells are *water*-filled	1 Transport of water, salts and air *across* root, either through or between cells 2 Some roots are storage organs – carrot
Vascular strand (stele)	1 A central *xylem* of vessels 2 Surrounding *phloem* of sieve tubes and companion cells 3 *Cambium* layer	1 Transport water and salts – transpiration 2 Translocation of organic food materials 3 Formation of new phloem and xylem tissues

3.11 QUESTIONS

1 What are the chief differences between plants and animals? Illustrate your answer by reference to *any named* animal or plant.

2 Describe the detailed structure of a *named* plant cell and a *named* animal cell. What structural features present in plant cells are absent in animal cells?

3 Compare the functions performed by a named living organism with a non-living motor vehicle.

4 Draw and describe the special functions of *two* examples of different cells found in a mammal and a flowering plant. Name the tissues and organs in which they are a part.

5 Give illustrated descriptions of the following: (a) enteron; (b) endoderm; (c) epithelium; (d) parenchyma; (e) chlorenchyma.

Table 3.3 *differences between plants and animals*

	Plants	*Animals*	*Exceptions*
Body structure	*Spreading*, *branching* body with large surface area. No main aperture. *External* organs, leaves and flowers	*Compact* body with less surface area. One main inhalent aperture. *Internal* organs, lungs and intestines. Enteron lined with endoderm	Jelly-fish have trailing organs
Nutrition	Carbon requirement comes from *carbon dioxide*. Nitrogen requirement comes from *nitrate* salts. Green plants make complex foods from *simple soluble* materials – photosynthesis	Carbon requirements come from *carbohydrates*. Nitrogen requirements come from *proteins*. Food is *complex* and *insoluble* from plant and animal sources	Non-green plants – fungi feed on complex insoluble foods. Certain plants can feed on insects – sundew
Movement	Non-motile, sessile or rooted in one place	Motile – moving freely from place to place	Sponges are sessile. *Chlamydomonas* is motile
Energy needs	Energy requirements are very small	Considerable energy required, with special *oxygen carriers* in blood	*Chlamydomonas* has high energy need. Tapeworm has low energy need
Excretion	Simple chemical waste materials, water and carbon dioxide. No special excretory organs	In addition to water and carbon dioxide, *complex nitrogenous* waste produced requiring special *excretory organs*	Fungi and insect-eating plants produce nitrogenous waste materials
Growth	At stem and root tip growing points. Continuous throughout organism's life	All over the body, continuous until organism is adult	
Sensitivity	No sense organs. *Slow* response to changes in surroundings. Control is *chemical*	Sense organs present. *Rapid* response to changes in surroundings. Control is chemical and *nervous*	*Amoeba* shows slow response

6 The following figures indicate the number of the different blood cells in one cubic millimetre (1 mm^3) of human blood:

Red blood cells	5400 000
White blood cells	8 000
Platelets	250 000

Display these figures graphically for comparison.

7 Draw and label *general* diagrams showing the structure of a dicotyledon stem and root seen in transverse section. List the main tissues and describe their functions.

8 Compare how a unicellular organism is able to perform all its life processes in one cell, whilst an isolated cell from a multicellular organism is unable to do so.

CHAPTER 4

BIOCHEMICAL PRINCIPLES

4.1 CHEMICAL ELEMENTS

Chemistry is the study of the composition of living and non-living substances. *Biochemistry* is the study of the chemical substances and chemical processes of living things.

All substances are composed of *chemical elements*, each of which consists of similar atoms. There are over 100 different chemical elements composing the Earth's living and non-living substances.

The *atom* is the smallest part of a chemical element which can take part in a chemical reaction. During chemical reactions, atoms are rearranged. Living substances rearrange atoms in biochemical processes.

A *symbol* is a shorthand method of representing *one* atom of a chemical element, and is written as a capital letter alone or with a small lower case letter.

Table 4.1 gives the names and symbols of some chemical elements of biological importance.

4.2 CHEMICAL COMPOUNDS

Chemical compounds are composed of *two* or more chemical elements joined together by chemical bonds. After combining together, the properties of the chemical elements are changed.

A *molecule* is the smallest part of a substance, whether it is an element or compound, that is able to exist on its own. The molecule is the smallest part of hydrogen, oxygen or water that is able to exist alone. Atoms are *unable* to exist on their own.

A *chemical formula* is a shorthand method for representing *one* molecule of a compound or element. A formula is written using the chemical symbols and indicating numbers to show how many component atoms are present in a molecule.

Table 4.1 *chemical elements of biological importance*

Non-metals		*Metals*	
Element	*Symbol*	*Element*	*Symbol*
Hydrogen	H	Sodium	Na
Carbon	C	Magnesium	Mg
Nitrogen	N	Potassium	K
Oxygen	O	Calcium	Ca
Phosphorus	P	Iron	Fe
Chlorine	Cl	Zinc	Zn
Iodine	I	Copper	Cu
Fluorine	F	Manganese	Mn

Water has the chemical formula H_2O; its molecule consists of *two* atoms of hydrogen and *one* atom of oxygen, and altogether three atoms compose the water molecule. Oxygen gas has the formula O_2; this means that *two* atoms of oxygen form the molecule. The symbol O represents *one* oxygen atom and this is unable to exist on its own; it exists only when combined with another oxygen atom.

The following chemical formulae should be known by students of biology: water, H_2O; oxygen, O_2; hydrogen, H_2; glucose, $C_6H_{12}O_6$; carbon dioxide, CO_2; ammonia, NH_3; ethanol, C_2H_5OH; and carbamide (urea) $CO(NH_2)_2$.

Experiment 4.1 ***to show the chemical elements present in living things and foods*** **(Fig. 4.1)**

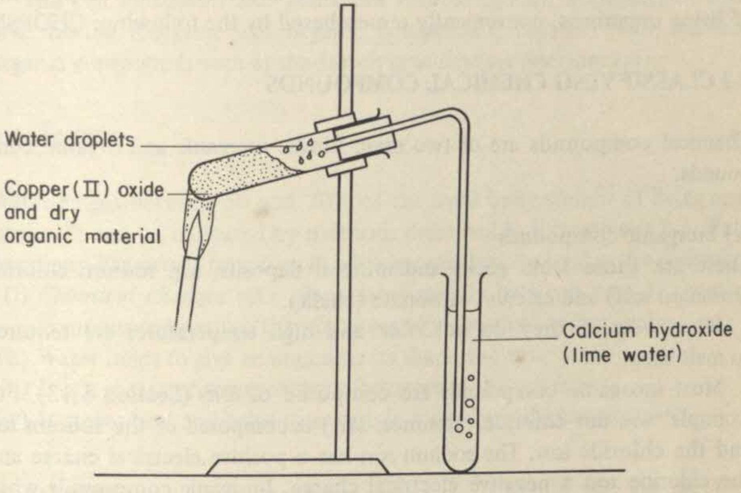
Procedure A

(i) Connect a hard glass test tube to a cork fitted with a delivery tube dipping into clear calcium hydroxide (lime water) solution.

(ii) Dry some grass cuttings in an oven at 110°C, or obtain some *dried* milk powder. Mix the dried substance with an equal amount of powdered black copper(II) oxide. Place the mixture in the hard glass test tube supported by a retort stand and clamp.

(iii) Gently heat the mixture with a *small* burner flame, and observe how the calcium hydroxide changes its appearance, and how droplets of liquid collect on the cooler parts of the test tube.

fig 4.1 *testing for the presence of the chemical elements carbon and hydrogen in organic material*


Water droplets
Copper (II) oxide and dry organic material
Calcium hydroxide (lime water)

Observations

A *chemical reaction* occurs between the dried substance and the copper(II) oxide. During this chemical change, *oxygen* is added to *carbon* and *hydrogen* present in the dried grass or milk to form carbon dioxide, CO_2, and water, H_2O. The carbon dioxide also causes a *chemical change* to occur in the calcium hydroxide (lime water), which becomes cloudy. The water forms droplets by means of condensation in a *physical change* from vapour to liquid.

This test is a way of showing that the grass or milk contains the chemical elements *hydrogen* and *carbon.*

Procedure B

(i) Mix together equal amounts of dry grass or dried milk with *soda lime*, and place the mixture in the same apparatus as in Procedure A but omit the test tube of calcium hydroxide.

(ii) Gently heat the mixture and hold a moist red litmus paper or yellow turmeric paper in the issuing fumes. Red litmus turns blue, and turmeric paper turns brown in the presence of *ammonia*, which forms from any compound containing the element *nitrogen*.

Hold a moistened lead ethanoate (acetate) paper in the vapour; this turns black due to hydrogen sulphide formed from any compound containing *sulphur*.

Dried grass and milk contain the chemical elements carbon, hydrogen, sulphur and nitrogen. Oxygen is also present but cannot be shown by simple tests.

These five chemical elements and phosphorus are important components of living organisms, conveniently remembered by the following: CHOPSN.

4.3 CLASSIFYING CHEMICAL COMPOUNDS

Chemical compounds are of two main kinds: *inorganic* and *organic* compounds.

(a) Inorganic compounds

These are those from rocks and mineral deposits, e.g. sodium chloride (common salt) and calcium carbonate (chalk).

When *heated*, they do not *char* and high temperatures are required to melt them.

Most inorganic compounds are composed of *ions* (Section 5.13). For example, sodium chloride (common salt) is composed of the sodium ion and the chloride ion. The sodium ion has a positive electrical charge and the chloride ion a negative electrical charge. Inorganic compounds when dissolved in water of the soil, or in the living cell, will be present as *ions*.

(b) Organic compounds

These are formed by living organisms, e.g. sucrose (cane sugar) in sugar cane and beet plants, lard in pork fat, vitamin C in oranges.

When *heated*, they char or blacken easily, showing that they are compounds of the element *carbon* (soot and charcoal). They also *melt* at low temperatures. Organic chemical compounds contain a few chemical elements, of which C, H, O, P, S and N are the main ones, whilst inorganic compounds are made up from any of 100 different chemical elements combined in different ways.

Organic compounds, in contrast to inorganic compounds, do not usually form *ions*. Many organic compounds have molecules which are much larger than inorganic compound molecules, and such large organic molecules are called *macromolecules* (see Plate 11.1).

4.4 MIXTURES

A *mixture* can contain two or more different substances which are either elements or compounds. The components of a mixture are not joined by chemical bonds and are easily separated.

Air is an important biological mixture; it is composed of elements and compounds. The *elements* are oxygen and nitrogen together with small amounts of certain inert gases; the *compounds* include carbon dioxide and water vapour. Other compounds may be present as *pollutants* (Section 20.6).

The cell *cytoplasm* and plant cell *vacuole* contain a mixture of water and *soluble* inorganic and organic compounds, together with *insoluble* organic compounds such as the starch granules (see Section 3.4).

4.5 WATER

Water forms between 50 and 70% of the total body weight of living organisms. It can be estimated by methods described in Experiment 8.3. Water has many important functions in a living organism, including the following:

(i) *Chemical changes* take place more rapidly between *ions* of chemical compounds in water, than between *dry* chemical compounds.
(ii) Water helps to give an organism its shape and *structure*.
(iii) It is a means of *transporting* substances in the organism.
(iv) It stores heat and helps to maintain a steady *body temperature*.

4.6 ACIDS

Acids are compounds the solutions of which contain *hydrogen ions*, and turn neutral litmus paper red.

The most important *inorganic* acids in living organisms are *carbonic acid*, H_2CO_3, and *hydrochloric acid*, $HC1$, whilst the organic acids of importance include *lactic acid, citric acid* and the *amino acids*. Inorganic acids are strongly corrosive, whilst organic acids are very weak and without corrosive properties.

4.7 BASES

Bases are compounds which react with acids. The water-soluble bases are called *alkalis*, for example ammonium hydroxide, NH_4OH. Bases turn neutral litmus paper *blue*.

The *organic bases* are mainly called *amines*, and are listed in Table 4.2. Inorganic bases are strongly corrosive, whilst organic bases are much weaker and without corrosive properties. Amides are related compounds, for example carbamide (urea).

4.8 SALTS

A *salt* is formed when an acid reacts with a base, to replace the acid's

Table 4.2 *bases of biological importance*

Name	*Component elements*	*Function*
Inorganic bases		
Ammonium hydroxide	N, H, O	Soil fertility, excretion
Calcium hydroxide	Ca, O, H	Soil fertility
Organic bases		
Amines of different kinds	C, N, H	Excretory products
Purine bases:		
adenine, guanine	C, N, H	Nucleic acids, DNA and RNA
Pyrimidine bases:		
thymine, cytosine	C, N, H	Nucleic acids, DNA and RNA

hydrogen by a *metal* or *ammonium* radical:

acid + base → salt + water

Note that water is an important product.

A salt will be composed of two parts or *ions*, one due to the metal or ammonium group, and the other due to the acid radical group of atoms. The important *acid radicals* in biology are chloride, nitrate, sulphate and *phosphate*.

SALT

metal or
ammonium
ion

acid radical ion:
chloride, sulphate,
nitrate, phosphate

Most salts are *neutral* to litmus when dissolved in water. Some salts, e.g. ammonium chloride (NH_4Cl), are *acid* to litmus, and others, e.g. sodium hydrogen carbonate (bicarbonate), are *alkaline* to litmus.

4.9 THE pH SCALE

Litmus is one example of an *indicator* able to detect acidity or alkalinity; there are other indicators which include *methyl orange*, or the 'Universal Indicator'.

The pH or hydrogen-ion concentration scale ranges from pH 1 to pH 14. Solutions with a pH value of *less* than *seven* are *acidic*, whilst solutions with a pH *more* than *seven* are *alkaline*. A solution with a pH of *seven* is *neutral*.

1 ——————— 7 ——————— 14

acidic neutral alkaline

The *strong* bases and acids have pH values of 14 and 1 respectively whilst *weak* bases and acids have pH values of 8 and 6.

Experiment 4.2 *to determine pH of solutions*

Procedure

(i) Obtain a *wide-range* 'Universal Indicator' pH paper, together with its colour chart.

(ii) Test the pH of different solutions, tap water, pond water, saliva, urine, milk and vinegar.

(iii) Compare the colour produced after dipping the pH paper in the solution with the pH colour chart, and read off the pH value. Use a *narrow-range* indicator paper for a more accurate pH value.

(a) Buffer solutions

These are solutions in which the pH remains *unchanged* after diluting it with water, or adding acid or alkali. This is important in and around cells where the fluid pH must be kept constant, for example blood pH is 7.4. Certain substances called proteins act as buffers in living organisms. This constant pH is important in *homeostasis* (Sections 3.1 and 12.1). The buffer 'mops up' any acidity or alkalinity which may develop to upset the normal pH.

4.10 CHEMICAL REACTIONS

When two or more substances interact chemically, a *chemical change* will occur with *new* substances or *chemical products* being formed.

All the chemical reactions which take place in living *cells* are called *metabolism* or metabolic changes.

Physical changes contrast with chemical changes in being a temporary and *reversible* change for a substance, and no new substances are formed. For example, food can be changed physically when *chewed*, or lungs inflated and deflated change in *size*.

There are a great number of different chemical changes taking place in a living cell, and like those occurring in a *test tube* they are affected by *temperature*. An *increase* of ten degrees centigrade (10°C) will make the rate of chemical reaction *double*, and a similar *decrease* will *halve* the rate of chemical reaction.

Certain *substances* called *catalysts* can alter the rate of a chemical reaction but are themselves unaffected by the change.

Experiment 4.3 *to show the effect of a catalyst*

Procedure

(i) Mix one part of 20 volumes hydrogen peroxide solution with four parts of water. Place a 10 cm^3 portion in five test tubes.

(ii) Sprinkle a *pinch* of dry sand in one test tube, and powdered manganese dioxide in another. Observe foaming. Test the issuing gases with a glowing wood splint; this will relight if oxygen is evolved.

(iii) Add a piece of *fresh* carrot, fresh meat and apple to separate test tubes. Note any foaming.

Observations

Manganese dioxide is a *chemical catalyst* which brings about a chemical change in which hydrogen peroxide is *decomposed* into water and oxygen. *Fresh* carrot, meat and apple contain *biological catalysts*, also called *enzymes* (Section 4.14), in the living cells, also capable of decomposing hydrogen peroxide.

(a) Chemical reactions of biological importance

(i) *Anabolism and catabolism*

The main chemical reactions occurring in cells are either (1) *synthesis* or building-up of a compound from *simpler* substances, which is also called *anabolism*; or (2) *decomposition* or breakdown of chemical compounds also called *catabolism*.

(ii) *Endothermic and exothermic reactions*

Chemical reactions such as synthesis take in *energy* and are called *endoergic*; if the energy is in the form of heat, it is *endothermic*. Decomposition reactions give *out* energy and are *exoergic*; if this is in the form of heat, it is an *exothermic* reaction.

Table 4.3 summarises some of the more important chemical reactions occurring in some plant and animal cells.

(b) Chemical equations

Chemical *equations* are used to represent chemical reactions using symbols and formulae.

The construction of a chemical equation requires a knowledge of the chemical formulae for the reacting substances, or *reactants*, and the *products*. Alternatively a *word equation* can be used.

Table 4.3 *chemical reactions of biological importance*

Chemical reaction	*Change that takes place*
Exothermic reaction – exoergic	Heat energy released to the surroundings – respiration
Endothermic reaction – endoergic	Heat energy taken in from surroundings as for most life processes
Neutralisation	Reaction between *acid* and *base* to form a *salt* and *water*. Removal of harmful waste in excretion
Hydrolysis	Breakdown or splitting of chemical substances by *water.* Occurs in food digestion
Condensation	A chemical change in which *water* is formed by joining together of two compounds. Occurs when food is stored. Reverse of hydrolysis
Oxidation (dehydrogenation)	A process of joining with oxygen or removing hydrogen. Occurs in respiration
Reduction	A process of adding hydrogen or removing oxygen. Reverse of oxidation.
Dehydration	Removal of water from substances
Deamination	Removal of *amino* group from amines and amino acids. Occurs in animal liver cells
Polymerisation	Joining together of *small* molecules, *monomers*, to form *large* molecules called *polymers* or macromolecules such as proteins and polysaccharides

(i) *Neutralisation*

This can be shown by the word equation:

$$\text{acid} + \text{base} \rightarrow \text{salt} + \text{water}$$

$$\begin{matrix}\text{hydrochloric}\\ \text{acid}\end{matrix} + \begin{matrix}\text{sodium}\\ \text{hydroxide}\end{matrix} \rightarrow \begin{matrix}\text{sodium}\\ \text{chloride}\end{matrix} + \text{water}$$

(ii) *Hydrolysis*

$$\text{salt} + \text{water} \rightarrow \text{acid} + \text{base}$$

$$\begin{matrix}\text{sodium}\\ \text{hydrogen}\\ \text{carbonate}\end{matrix} + \text{water} \rightarrow \begin{matrix}\text{carbonic}\\ \text{acid}\end{matrix} + \begin{matrix}\text{sodium}\\ \text{hydroxide}\end{matrix}$$

(iii) *Oxidation*

$$\text{element} + \text{oxygen} \rightarrow \text{element oxide}$$

$$\text{carbon} + \text{oxygen} \rightarrow \text{carbon dioxide}$$

(iv) *Reduction*

$$\text{element oxide} + \text{hydrogen} \rightarrow \text{element} + \text{water}$$

$$\text{copper(II) oxide} + \text{hydrogen} \rightarrow \text{copper} + \text{water}$$

(c) Reversible chemical reactions

An arrow indicates the *direction* in which the chemical reaction is occurring. The following reaction occurs in plant food *synthesis* (Section 6.1):

$$\begin{matrix}\text{carbon}\\ \text{dioxide}\end{matrix} + \text{water} + \text{energy} \rightarrow \text{glucose} + \text{oxygen}$$

The reverse reaction occurs in food *decomposition* by respiration (Section 10.1):

$$\text{glucose} + \text{oxygen} \rightarrow \begin{matrix}\text{carbon}\\ \text{dioxide}\end{matrix} + \text{water} + \text{energy}$$

4.11 **LIPIDS**

These are the *fatty* or *oily* organic compounds which consist of *two* main components, the fatty (alkanoic) acids and glycerine (propane-1,2,3-triol). Other lipids are the *waxes* found in insect beeswax, and coating a leaf surface.

lipid → fatty acids + glycerine
(alkanoic acids) (propanetriol)

Lipids consist of carbon, hydrogen and oxygen (C, H, O) with a higher proportion of carbon than the other two elements.

Lipid *oils* are liquids at room temperature, e.g. olive oil. Lipid *fats* are solid at room temperature, e.g. lard. Note that liquid paraffin is a *hydrocarbon* oil containing only carbon and hydrogen; hydrocarbons cannot be used as a source of energy by living organisms.

Experiment 4.4 *testing for the presence of lipids*

Procedure

(i) Press the sample on a piece of writing paper, and hold to the light and note the formation of a translucent *grease spot*.
(ii) Sudan III stain when added to thin sectioned material and viewed by a light microscope will show the stain taken up by lipid tissues.

4.12 CARBOHYDRATES

There are *three* main kinds of carbohydrate organic compounds, all of which are composed of carbon, hydrogen and oxygen chemical elements (C, H, O).

(a) Monosaccharides

These are small-molecule *sugars*. *Ribose* has five carbon atoms in a molecule, $C_5H_{10}O_5$. A closely related sugar, *deoxyribose*, has one oxygen atom *less* than ribose, $C_5H_{10}O_4$.

Glucose (blood sugar), fructose (fruit sugar) and galactose (part of milk sugar) have six carbon atoms to a molecule, $C_6H_{12}O_6$.

(b) Disaccharides

These are small-molecule sugars, and include sucrose (cane sugar), maltose (malt sugar) and lactose (milk sugar). All have 12 carbon atoms in a molecule, $C_{12}H_{22}O_{11}$.

(c) Polysaccharides

These are macromolecules built up from *units* of monosaccharide sugars, joined together in long-chain molecules to form *cellulose, starch* and *glycogen*, all of which are built up from glucose units (see Section 3.4).

Related compounds include *chitin* found in arthropods, and the *mucopolysaccharides* which are components of the lubricant *mucin*, and *intercellular cement* of animal cells (see Section 3.6).

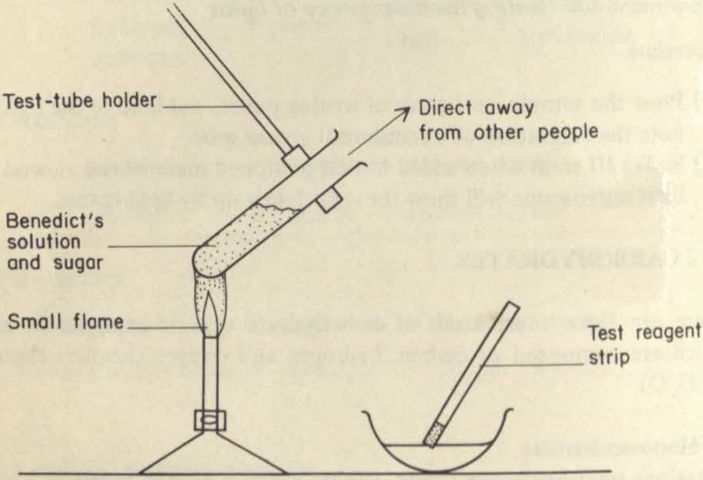
Experiment 4.5 *testing for the presence of carbohydrates* (Fig. 4.2)

Procedure A: reducing sugars (glucose, fructose and maltose)

(i) Add the sugar to 5 cm^3 of Benedict's solution in a test tube. Bring to boil slowly and observe that a yellow-green-red coloured *precipitate* or insoluble substance is formed.

(ii) Dip a 'Clinistix' reagent strip into the substance. The reagent area turns from red to purple in colour with *glucose*.

fig 4.2 *testing for presence of carbohydrates in a food sample*



Procedure B: non-reducing sugar (sucrose)

(i) Sucrose does not affect Benedict's or 'Clinistix' reagents. To the sucrose solution, add one drop of dilute hydrochloric acid and boil for 2 min. This causes *hydrolysis* of sucrose into glucose. Test the solution with either Benedict's or 'Clinistix' reagent.

(ii) Alternatively, add a drop of Seliwanoff's reagent to a few drops of sucrose solution on a clean microscope slide, and hold over a small flame to heat gently. A red colour forms showing that the sugar is sucrose.

Procedure C: starch

(i) Add a few drops of iodine in potassium iodide solution to starch solution in a test tube. Observe the blue-black colouration.

(ii) Heat the test tube and its contents and note the disappearance of the colour. Cool the test tube in cold water and note that the colour reappears.

4.13 PROTEINS

Proteins are *macromolecules* composed of carbon, hydrogen, oxygen and nitrogen, and may also contain sulphur and phosphorus in certain proteins (C, H, O, N + S, P).

The *unit* or monomer composing the macromolecule of proteins is called the *amino acid*, of which there are *twenty* different kinds in living cells. The different amino acids are joined together in long protein *chain* molecules.

The following are names of the more common amino acids which end in *–ine* or are called *acid*: alanine, serine, cysteine, aspartic acid, glutamic acid and leucine.

The proteins are classed as follows:

(a) Fibrous proteins

These have molecules resembling coiled springs and are present in hair, hoof and horn *keratin*; skin tendons and ligaments as *collagen*; muscle, *myosin*; and *elastin* in cartilage. They are *structural* proteins.

(b) Globular proteins

These have molecules with an irregular shape and are called *functional* proteins since they take part in chemical reactions as *enzymes, hormones* and blood *antibodies.*

(c) Conjugated proteins

These are composed of a non-protein and protein component, e.g. the cell membrane *lipoprotein*, and the *nucleoproteins* associated with a cell nucleus.

Experiment 4.6 *testing for the presence of proteins*

Procedure

(i) When a few drops of dilute nitric acid are added to the protein substance and gently heated (CARE!!) and a drop of dilute ammonium hydroxide added, the protein turns a yellow-orange colour.

(ii) Repeat Experiment 4.1, Procedure B, and test fumes for ammonia with moist red litmus or turmeric papers.

(iii) Dip an 'Albustix' reagent strip in the protein substance and the reagent area turns from yellow to green in colour with most proteins.

4.14 ENZYMES

Enzymes are *proteins* found in every living cell and act as *catalysts* to bring about chemical changes in living cells. They are *specific* in their action; the *glycosidase* enzymes act on carbohydrates, *lipases* act on lipids and *proteases* act on proteins.

Enzyme names end in *–ase* or a few end in *–in* (pepsin).

(a) Conditions for enzyme action

The enzymes work rapidly provided the following *conditions* are available:

(i) A *certain pH* is required. Acidity or pH 2 is needed for stomach digestive enzymes, whilst slight alkalinity pH 8 is needed for small intestine digestive enzymes (see Section 7.7).

(ii) A *temperature* of near blood heat, 38°C, is needed. Above 45°C the enzyme activity declines until at high temperatures the protein is *coagulated*. For each 10°C rise the rate of enzyme action is doubled, below 45°C.

(iii) Certain minerals and vitamins are needed for enzyme activity.

(iv) Poisons, arsenic, lead and cyanide destroy enzyme activity.

Experiment 4.7 *to show the effect of high temperature on enzymes*

Procedure

Repeat Experiment 4.3 and use *boiled* and cooled meat, carrot and apple.

Boiling destroys or coagulates the enzyme proteins, rendering them inactive. Catalase is the enzyme present in living cells and is able to decompose hydrogen peroxide.

4.15 NUCLEIC ACIDS – POLYNUCLEOTIDES

A *nucleotide* is an organic compound composed of three parts: (a) *phosphate* radical, (b) *ribose* sugar, and (c) an organic *base* such as purine or pyrimidine:

$$\text{nucleotide} = \begin{matrix}\text{organic}\\ \text{base}\end{matrix} + \begin{matrix}\text{ribose}\\ \text{sugar}\end{matrix} + \text{phosphate}$$

A *polynucleotide* is a macromolecule made up of many nucleotide units forming the two *nucleic acids*, ribonucleic acid, RNA, containing *ribose* sugar, and deoxyribonucleic acid, DNA, containing *deoxyribose* sugar (see Section 4.12):

$$\begin{matrix}\text{ribonucleic acid}\\ \text{or RNA}\end{matrix} = \text{ribose} + \begin{matrix}\text{organic}\\ \text{base}\end{matrix} + \text{phosphate}$$

$$\begin{matrix}\text{deoxyribonucleic}\\ \text{acid or DNA}\end{matrix} = \text{deoxyribose} + \begin{matrix}\text{organic}\\ \text{base}\end{matrix} + \text{phosphate}$$

The DNA molecule is a *double-stranded* spring shape or *coil* (see Plate 11.1). A *related* compound is adenosine triphosphate or ATP (Section 10.1 and 16.4). Nucleic acids are found in the cell nucleus and cytoplasm.

4.16 QUESTIONS

1 List the main chemical elements present in living organisms. Which chemical elements are present in proteins, carbohydrates and lipids?

2 Explain the chemical changes of neutralisation and hydrolysis. What are the products of hydrolysis of proteins, lipids and polysaccharides?

3 Describe simple chemical tests for proteins, lipids, reducing sugars and polysaccharides. Indicate which of the following substances would give positive results to the chemical tests: glucose, egg white, starch, amylase, insulin, sucrose and olive oil.

4 What substances are taken in by living organisms in the form of *ions*? Give names of three substances in each case which have pH values of 1 to 6 and 8 to 14. Which substance has a pH of 7? How can pH be measured?

5 The following represent the percentage component elements of a living organism. Draw a pie diagram using these figures:

Hydrogen	10.0%	Carbon	20.0%
Nitrogen	2.5%	Oxygen	63.0%
Phosphorus	1.0%	Other elements	3.5%

CHAPTER 5

BIOPHYSICAL PRINCIPLES

5.1 MOVEMENT OF MOLECULES

Physics is the study of substances in relation to *energy* and in *measuring* certain properties of substances. *Biophysics* is the application of physics to the study of living organisms.

(a) States of matter

Matter is anything that occupies space and has mass or weight. It exists in three physical states, *solid, liquid* and *gas*. All substances found in living organisms exist in *one* of these physical states. For example, air is a gas, urine is a liquid and bone is a solid.

All substances and matter are composed of *molecules* or *ions* (Sections 4.2 and 5.13).

(i) *Solids* have molecules closely packed together giving them a *definite* shape and volume.

(ii) *Liquids* have molecules spaced further apart, and they have a definite volume but no definite shape and take up the shape of the container which holds them, e.g. the urinary bladder, and xylem vessels.

(iii) *Gases* have molecules *widely* spaced apart and consequently they have no definite shape, and take the space of the container which holds them, e.g. the lung, or spaces in the leaf.

Experiment 5.1 *observing the effect of moving molecules*

Procedure

(i) Place water in a cavity microscope slide and add *one* drop of Indian ink or shake *pollen* from a flower onto the water.

(ii) Keep the microscope steady and observe the ink or pollen particles through a light microscope.

Observations

The particles show an irregular zig-zag movement caused by the collision of continually *moving* water molecules. The water molecules are invisible but their effect on the ink and pollen particles is visible *evidence*. This is known as *Brownian movement*, after the botanist Robert Brown (1773-1858) who first observed the phenomenon.

5.2 SOLUTIONS

(a) True solutions

A *true solution* is an even mixture of molecules of two different substances, and usually applies to a *solid* dissolved in a *liquid*. It also includes gases (air) dissolved in liquid (water), or liquids (ethanol) dissolved in another liquid (water).

The substance which dissolves is called the *solute* (e.g. sodium chloride), and the liquid which has the power of dissolving is the *solvent*. Thus sea water is partly a solution of salt solute in a solvent, water.

(b) Concentration

This is the amount of a substance in a known amount of solution. It is measured as the *mass* or *weight* in 100 cm^3 or one litre of water. Usually it is more convenient to describe it as a *percentage* weight in a volume of solvent. A 10% sugar solution contains 10 g in 100 cm^3 of water.

(c) Suspensions

These are mixtures of very small insoluble solid particles in a liquid. For example, *blood* is a suspension of blood cells in blood fluid, and starch granules are in suspension in cytoplasmic fluid. Suspensions can be separated by filtration to produce an insoluble *residue* on the filter, and a clear *filtrate* solution.

(d) Emulsions

These are mixtures of small droplets of one *insoluble* liquid, e.g. oil, in another liquid, e.g. water. Milk and cell cytoplasm contain oil droplets suspended in water as emulsions. The oil droplet has a high surface area/volume *ratio*.

(e) Colloidal solutions

These are solutions in which the solute is *intermediate* in size between that of particles in a true solution and a suspension. A colloidal solution appears *translucent*, compared to a *transparent* true solution, and an *opaque* suspension.

Colloidal solutions are found in the cell *cytoplasm* and are composed of *macromolecules* of proteins, e.g. enzymes, gelatine and egg white albumen or carbohydrates such as *soluble* starches.

Colloidal solutions cannot be separated by filtration, and they remain translucent after filtration.

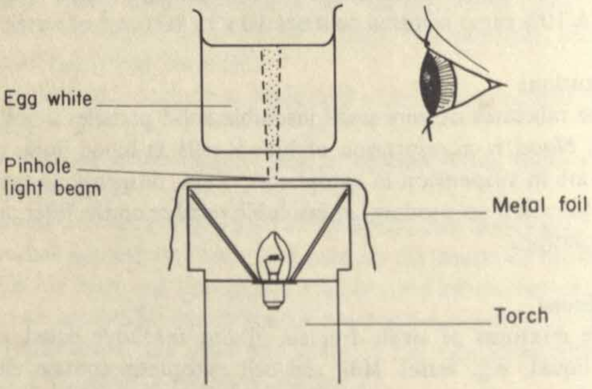
The colloidal particles have a high surface area/volume *ratio* and allow certain chemical changes to occur on their surfaces, as for example the colloidal *enzymes*.

Experiment 5.2 *to observe a colloidal solution* (Fig. 5.1)

Procedure

(i) View a sample of gelatine or egg white through a light microscope.
(ii) Place a gelatine solution or egg white in a small 50 cm^3 beaker. Cover a pocket torch glass with aluminium foil and pierce a small hole in it to produce a light *beam*.
(iii) Apply the torch to the bottom of the beaker and view the solution from the side in a dark room.

fig 5.1 *to demonstrate the Tyndall effect in colloidal solutions*



Observations

The light microscope shows a *clear* solution. Viewing the colloidal solution sideways shows the light beam *scattered* by invisible particles in the light path. A similar scattering of light is seen when a sunlight beam passes through dust-laden air. This is called the *Tyndall effect* after John Tyndall (1829–1893), a physicist.

Some colloidal solutions are *viscous* and have *elastic* properties in the form of a jelly or *gel*, seen in cell nuclei and chloroplasts. The *liquid* colloidal solution is called a *sol*, seen in jelly before it sets.

5.3 MOVEMENT BY DIFFUSION

Diffusion is the *movement* of molecules or ions of a dissolved substance through a solvent, from a region of *high* concentration to one of a *lower* concentration until the concentration becomes *even* throughout the solution.

Diffusion occurs when molecules move along a *concentration gradient* from a *high* to a *low* concentration.

Experiment 5.3 *to observe diffusion in a solution* (Fig. 5.2)

Procedure

(i) Prepare a 10% solution of gelatine in water, and add a few drops of phenolphthalein indicator. Allow the solution to gel in a test tube.
(ii) Invert the test tube and support it by a retort stand and clamp, in a beaker containing dilute sodium hydroxide. Leave aside for 2 days.

Observations

The sodium hydroxide ions move *upwards* against the force of gravity through the gel from the solution of *high* concentration into the gel of *lower* concentration of alkali. The movement is traced by the *pink* colouration formed by the phenolphthalein indicator.

Diffusion also occurs in *gases*; this is evident when a perfume diffuses through the air in a room, until it is uniformly distributed in the air.

Experiment 5.4 *to observe gas diffusion* (Fig. 5.2)

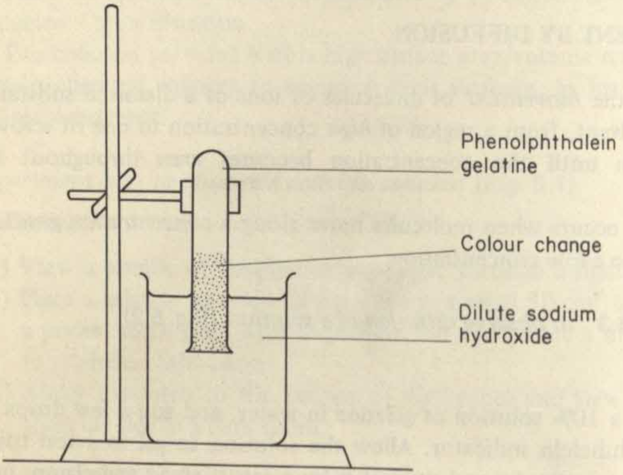
Procedure

(i) Insert a stopper in one end of a 20 cm combustion tube and insert a long length of pH 1–14 'Universal Indicator' paper along the inside of the tube. Dampen it with distilled water to fix it in position.
(ii) Insert a stopper, bored with a hole plugged loosely with cotton wool, into the open end.
(iii) Support the tube horizontally and soak the cotton wool plug with strong ammonium hydroxide solution.

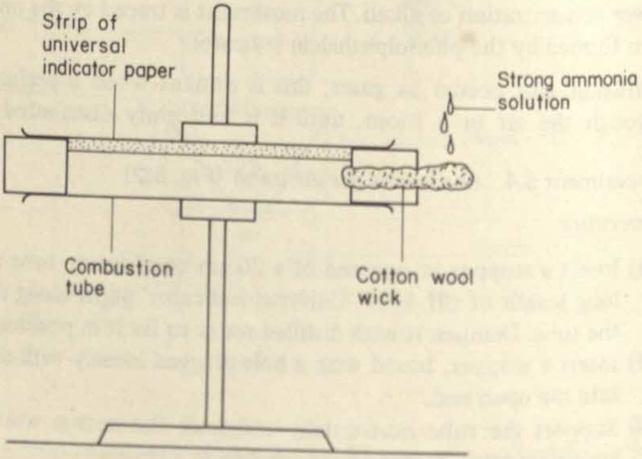
Observation

Note the *rapid* colour change of the 'Universal Indicator' paper from yellow to blue, as the ammonia gas diffuses through the tube.

fig 5.2 *to demonstrate diffusion in a liquid and a gas*



(a) Diffusion in solution



(b) Diffusion in air

5.4 PERMEABILITY

(a) Permeable materials

These will allow other substances, such as gases and liquids of a certain molecule size, to pass through the material. The plant cellulose cell wall is an important permeable substance.

(b) Filters

These are porous non-living materials such as filter paper, porous pot and fibreglass wool or cotton-wool. Filters have *large* pores which allow solutions and solvents to pass through but hold back large particles of *suspended* solids.

(c) Semipermeable membranes

The *cell membrane* or the plasma membrane of plant and animal cells is a *living* barrier called a selectively permeable membrane, or *semipermeable membrane*. Semipermeable membranes allow the passage of *some* substances but not others. The living semipermeable membrane of the plasma membrane allows water and fatty substances to pass through easily, but certain ions and proteins do not. The substances may pass through the semipermeable membrane by *dissolving* in it.

The *mechanisms* of transfer of substances across the plasma membrane include *diffusion, active transport* (Section 5.6), *osmosis, pinocytosis* (Section 7.8), *phagocytosis* (Sections 7.3 and 19.7), and *filtration* through pores.

Artificial non-living semipermeable membranes include certain compounds of cellulose, and Visking tubing.

Experiment 5.5 *to demonstrate the properties of porous and semipermeable materials* (Fig. 5.3)

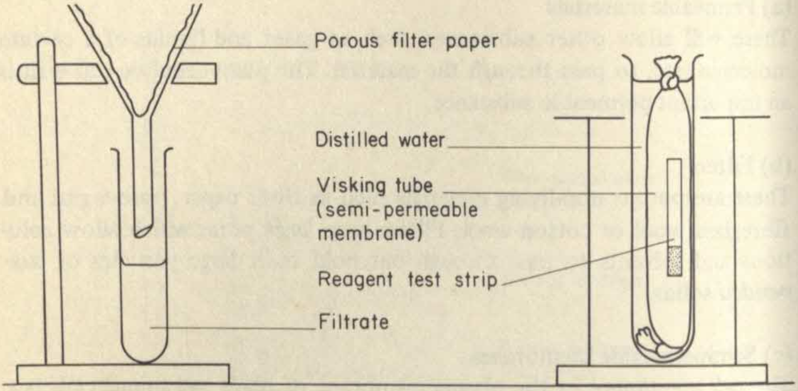
Procedure

(i) Prepare a mixed solution containing 5% sodium chloride, 5% glucose and 5% soluble starch.

(ii) Filter the solution through a porous filter paper. Test samples of the filtrate with a drop of silver nitrate for chloride, a 'Clinistix' reagent strip for glucose, and iodine solution for starch.

(iii) Cut a 20 cm length of Visking tubing, *semipermeable* membrane, and tie a knot at one end. Soak the tube in distilled water and pour the salt, glucose, starch solution into the Visking bag. Tie a knot in the open end to seal the bag. Thoroughly wash the outer surface in distilled water.

fig 5.3 *to demonstrate porous and semipermeable material properties*



(iv) Place the bag in a large test tube or beaker of distilled water. Leave for 1 h.

(v) Test samples of the surrounding water for chloride, glucose and starch as in (ii) above.

Observations

The porous filter allows *all* substances to pass through into the filtrate as shown by the chemical tests.

The *semipermeable* membranes only allow sodium chloride and glucose to pass through into the surrounding water. The colloidal macromolecule of starch is held back in the Visking bag. This is a method of separating colloidal and true solutions and is called *dialysis*.

5.5 OSMOSIS

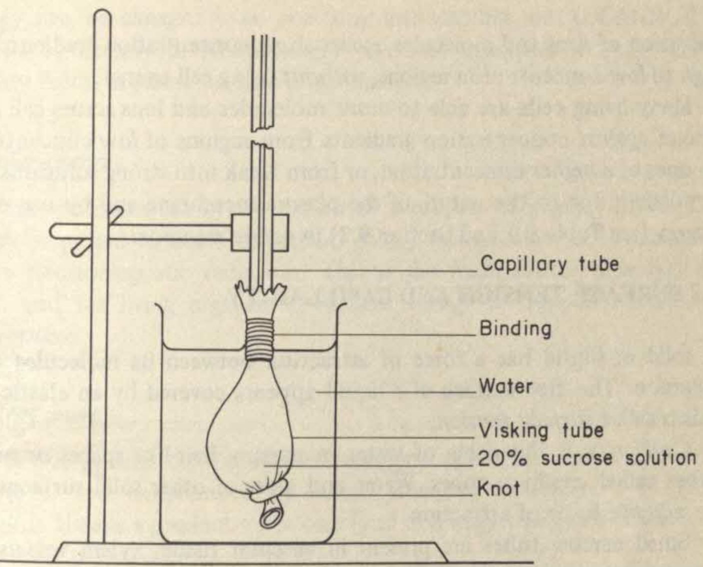
Osmosis is the passage of *water* across a *semipermeable* membrane from a solution of *lower* concentration to one of *higher* concentration, until both solutions are *equal* in concentration. (The definition should include *solvent*, and is omitted since *water* is the main biological solvent.)

Experiment 5.6 *to show osmosis* (Fig. 5.4)

Procedure

(i) Place a 20% sucrose solution in a knotted Visking tube and tie it firmly by strong thread to a glass capillary tube 30 cm in length. Support the tube upright by means of a retort clamp and stand. Keep the Visking bag immersed in a beaker of water.

fig 5.4 *demonstration of osmosis*



(ii) Note the initial position of the water in the capillary tube. Leave aside for 1 h.

Observations

Water passes by osmosis across the semipermeable membrane into the stronger solution of sucrose, causing the water level to rise in the capillary tube. The height to which the water rises is a measure of *osmotic pressure.*

Osmotic pressure is the pressure needed to *stop* water moving into the sucrose solution. The concentrated solution will therefore have a *higher* osmotic pressure than the water, or is *hypertonic*. The water is of lower osmotic pressure, or *hypotonic*. When osmotic pressures in solutions are *equal*, they are *isotonic.*

(a) Plasmolysis

When a green plant cell, e.g. onion bulb scale epidermis (Experiment 3.2), is placed in a *hypertonic*, e.g. 10% sucrose, solution, water is *withdrawn* from the cell. The cytoplasm shrinks away from the cell wall and the vacuole becomes smaller, this state being called *plasmolysis*. When the cell is placed in water or in a *hypotonic* solution, water *enters* the cell and the cytoplasm is pressed against the cell wall, and the cell vacuole increases in size, causing the cell to become *turgid*. The effect of plasmolysis on living cells is to make them *flaccid.*

5.6 ACTIVE TRANSPORT

Diffusion of ions and molecules occurs along concentration gradients from *high* to *low* concentration regions, *without* using cell energy.

Many living cells are able to *move* molecules and ions across cell membranes *against* concentration gradients from regions of *low* concentration to ones of a *higher* concentration, or from weak into strong solutions. This is possible due to the nature of the plasma membrane and by use of cell *energy* (see Table 9.1 and Section 9.2) in *active transport.*

5.7 SURFACE TENSION AND CAPILLARITY

A solid or liquid has a force of attraction between its molecules called *cohesion.* The free surface of a liquid appears covered by an elastic skin; this is called *surface tension.*

Capillarity is the rising of water in narrow hair-like spaces or narrow tubes called capillary tubes. Water and glass or other solid surfaces have an *adhesive* force of attraction.

Small narrow tubes are present in vascular tissue, xylem vessels, and narrow spaces are present between cells in *intercellular* air spaces.

Experiment 5.7 *to demonstrate capillarity*

Procedure

(i) Clip two clean microscope slides together with a paper clip at the narrow end and support a matchstick between the slides at the opposite end.

(ii) Place the slides lengthwise in a shallow dish of coloured water. Observe the rapid rise of water at the narrowest part between the glass slides.

5.8 ENERGY

Energy is defined as the means to do work. *Work* is done when a force pushes or pulls an object, causing it to *move* over a certain distance.

(a) Potential energy and kinetic energy

When a book is lifted up onto a shelf, work is done by a force providing the lift, to move the book over a certain distance. *Potential energy* is the energy possessed by a body by virtue of its *position*. For example, the book on the shelf has potential energy.

Kinetic energy is the energy possessed by a body by reason of its *motion*. For example, the book *falling* from a height can do *work* when it hits something.

(b) Other forms of energy

Energy can be *changed* from one form into another, but it CANNOT be created or destroyed. When energy seems to disappear, it reappears in another form, or passes on into *outer space.*

(i) *Solar energy*

The Sun produces energy by ***fusion*** or a process of joining atoms. This energy is passed to Earth as *radiant energy* (see Sections 5.11 and 5.12) called electromagnetic radiation. This is the main source of energy on Earth and for living organisms. Radiant energy is trapped by the cell *chloroplasts.*

(ii) *Heat energy*

This is energy that can be transferred from a place of ***high*** temperature to one of *low* temperature by means described in Section 5.11. Heat energy is always a product when one form of energy changes into another.

(iii) *Chemical energy*

This is energy released by chemical compounds, e.g. from food, from fuels, or from the energy-storing chemical compound in living cells, adenosine triphosphate (ATP).

(iv) *Electrical energy*

This is the energy produced by certain ions in living cells, particularly nerve cells.

(v) *Light energy*

This is a form of radiant energy which can be trapped by chloroplasts and can cause chemical changes and can bleach certain chemicals present in the vertebrate eye.

(vi) *Sound energy*

This travels as waves and causes vibration of the eardrum as kinetic energy of movement.

(vii) *Nuclear or atomic energy*

This is released as a result of atom *fission* or splitting (Section 5.13) in the nuclear reactor.

(c) Transducers

These are devices that change energy from one form to another. *Chloroplasts* change radiant energy into chemical energy. *Mitochondria* change chemical energy into kinetic energy. *Muscle* cells change chemical energy into kinetic energy. *Nerve* cells change chemical energy into electrical energy.

5.9 PRESSURE

Pressure is a force exerted by solids, liquids and gases acting on a unit area. It is equal to the mass or weight, divided by area:

$$\text{pressure} = \frac{\text{weight or mass}}{\text{area}}$$

It is measured in units called the pascal (Pa), named after Blaise Pascal (1623-1662):

$$1000\ \text{Pa} = \text{one kilopascal (1 kPa)}$$

(a) Pressure in water

A liquid such as water will exert a pressure which will *increase* with the *depth*. Similarly, the pressure in water at any point is transmitted equally in all directions.

Water pressure will have effects on *aquatic* organisms, and *high* pressures at great depths in oceans will restrict life to those organisms *adapted* to such high pressures.

(b) Air pressure

Air has weight or mass and forms a blanket around the Earth over 300 km high. Air exerts a pressure of about 100 kPa. The human body is therefore continuously subjected to a total air pressure of between 150 and 200 kPa.

5.10 BODIES MOVING IN FLUIDS

Animal bodies must move through *fluids*, either air or water. When a body moves rapidly through air or water, it experiences a retarding force or *drag*, which forms as eddies or whirls behind the object. In order to overcome this drag, a *streamlined* body shape is necessary (see Section 14.9). The *shape* of an organism is therefore important to its way of life.

The *aerofoil* or *hydroplane* is an important body structure seen as the wings of birds and fins of fish, and is the means of producing a lifting force called *lift*. When fluid air or water flows over a *tilted* wing or fin, the fluid moves *faster* over the top surface than over the lower surface. This causes a *decrease* in pressure above the wing or fin, resulting in an upward *lift.*

Experiment 5.8 *to demonstrate lifting force*

Procedure

Cut out a piece of paper about 20 cm x 10 cm. Hold the narrow end against your chin, just below your lips. Allow the paper to fold over and hang downwards. Blow over the paper's upper surface and watch how the paper is *lifted upwards* by the creation of low pressure.

5.11 HEAT

A body has a *temperature* which is determined by its *sensation* of relative hotness or coldness.

(a) Temperature

Temperature is a *number* which expresses the relative hotness or coldness on some chosen *temperature scale*. The *Celsius* scale of temperature has 0°C, or zero degrees Celsius, as its lower point at the temperature of melting ice, and 100°C as its upper point, the temperature of steam from boiling water. The scale was devised by Anders Celsius (1701-1744).

(b) Heat measurement

This is by means of instruments called calorimeters. Heat is measured in units called the *joule* (J); larger units include the kilojoule (kJ), or 1000 J, and the megajoule (MJ), or 1000 000 J (see Section 8.3). The joule is so-called after James Joule (1818-1889), a physicist.

(c) Heat transfer

Heat can travel from one point to another by three methods, conduction, convection and radiation.

(i) *Conduction*

This is the transfer of heat from a place of high temperature to one of lower temperature by molecular motion. In solids, the heat passes from particle to neighbouring particle.

Metals are good heat conductors, whilst non-metals such as wood and glass are poor heat conductors. Water is a poor conductor of heat, whilst air is the worst conductor, which in turn makes it a *good* heat insulator.

(ii) *Convection*

This is heat transfer in liquids and gases by the bodily movement of the heated particles. In this way, warm water rises above cold water, and warm air rises above cold air; this allows birds to *soar* in warm air.

(iii) *Radiation*

This is a method by which heat travels as rays or waves, called infra-red rays, and does *not* require atoms or molecules to carry it as does conduction or convection. The Sun and all hot bodies including living organisms emit heat or infra-red rays.

Dark rough surfaces are good radiant heat absorbers, whilst light smooth surfaces are good radiant heat reflectors.

(d) Specific heat capacity

The *same* weights of *different* substances will take up heat by different amounts.

The amount of heat required to raise the temperature of 1 kg of a substance by 1°C is called its *specific heat capacity*. For example, the specific heat capacity of *water* is 30 times that of mercury; this means it will take 30 times more heat to heat up water than the same weight of mercury.

Water will therefore heat *up* slowly compared to most other liquids, and will also *lose* heat slowly. This will provide living organisms, which consist of over 50% water, with fairly steady temperatures inside and around the cells.

(e) Evaporation

Evaporation is the change of physical state from a liquid to a vapour, without necessarily boiling the liquid.

The amount of heat needed to evaporate 1 kg of water is equal to 2260 kJ or 2.26 MJ, and is called the *latent heat of evaporation*. When water is on an animal's skin, it will *draw* heat by conduction from the animal's body in order to evaporate the water.

Experiment 5.9 *to show the relationship between surface area and evaporation*

Procedure

(i) Obtain a large and small potato. Peel them and carefully weigh each peeled potato and record the weight as A g.
(ii) Leave the peeled potatoes exposed to room air for 7 days. Reweigh them and record the weight as B g.
(iii) Calculate the percentage loss in weight by evaporation from:

$$\frac{A\text{ g} - B\text{ g}}{A\text{ g}} \times 100 = \begin{array}{l}\text{percentage loss}\\ \text{due to evaporation}\end{array}$$

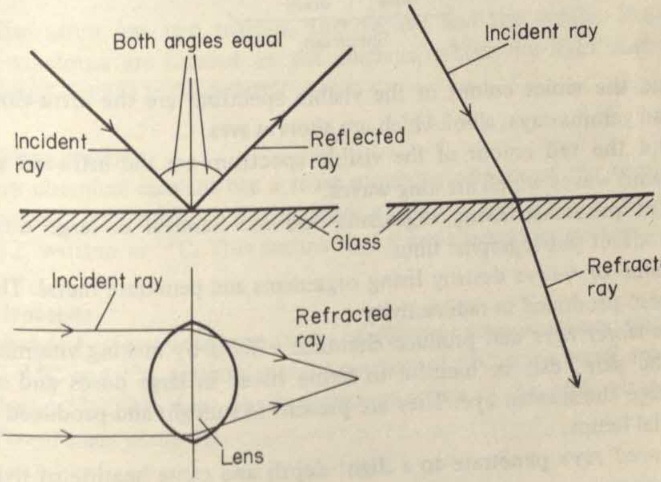
Observations

The small potato has a greater surface area/volume *ratio* compared to the large potato. Consequently, it should show the greater percentage loss of water due to evaporation.

5.12 LIGHT

Light can be *reflected* from a mirror and *refracted* and its direction altered as it passes from one substance into another (Fig. 5.5). Lenses are able to refract or bend light.

fig 5.5 *the behaviour of light rays*



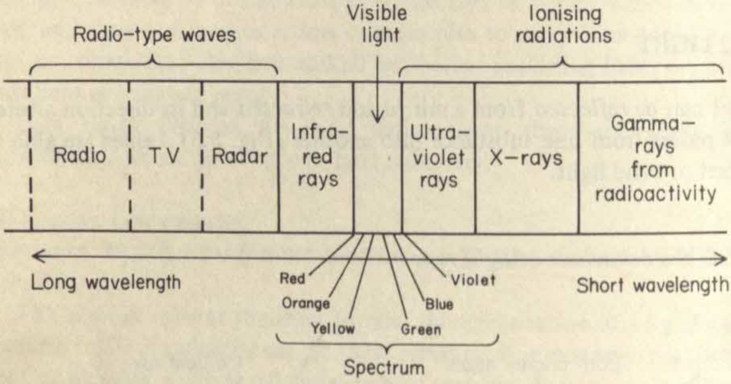
When sunlight or white light from a lamp passes through a triangular prism of glass, for example the edge of a bevelled mirror, it undergoes *dispersion*. Dispersion is the spreading out of light into the component colours of the *spectrum*: red, orange, yellow, green, blue, indigo and violet (ROYGBIV). Red is the least-refracted colour and violet the most-refracted colour. White light is therefore a mixture of seven different spectrum colours.

A *green* leaf appears green since the chloroplasts absorb mainly red and blue, and *reflect* the green, yellow and orange colours.

(a) Electromagnetic waves

Light, infra-red and radio waves are called electromagnetic waves; they are parts of the *electromagnetic spectrum* (Fig. 5.6) which is mainly *invisible* apart from the visible light spectrum, ROYGBIV.

fig 5.6 *the electromagnetic spectrum*



Beyond the violet colour of the visible spectrum are the ultra-violet, X-rays and gamma-rays, all of which are *short* waves.

Beyond the red colour of the visible spectrum are the infra-red and various radio waves which are *long* waves.

(i) *X-rays* penetrate living organisms and are harmful in large doses; they affect photographic films.

(ii) *Gamma- or γ-rays* destroy living organisms and penetrate metal. They are also produced in radioactivity.

(iii) *Ultra-violet rays* can produce chemical effects by making vitamin D in the skin, can be harmful to living tissue in large doses and can damage the human eye. They are present in sunlight and produced by special lamps.

(iv) *Infra-red rays* penetrate to a slight depth and cause heating of living organisms.

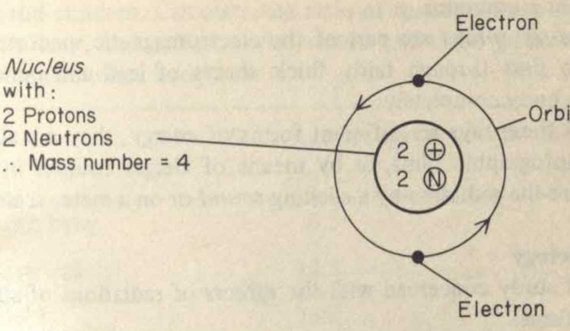
(v) *Radio waves* include microwaves which penetrate living tissue and cause harmful heating effects. Radar, television and sound radio are sent over long distances and are harmless to living organisms.

5.13 ATOMIC STRUCTURE

(a) Atoms

The atom (Section 4.1) is known to be composed of three main atomic particles: the *electron, proton* and *neutron* (Fig. 5.7).

fig 5.7 *the structure of the helium atom*



(i) *Electrons* are negatively charged and extremely light particles. A beam of electrons is used in the electron microscope.

(ii) *Protons* are heavy particles with a positive charge; this can neutralise the charge of an electron.

(iii) *Neutrons* are heavy particles without a charge.

The atom has two regions, the *nucleus* and the *orbits*. The protons and neutrons are located in the nucleus, whilst the light electrons are arranged outside in the *orbits*.

(b) Mass number

Every chemical element has a mass number made up of the total number of protons and neutrons in the atom nucleus. Carbon has a mass number of 12, written as ^{12}C. This means that it has six protons and six neutrons.

(c) Isotopes

A chemical element can have atoms of *different* mass numbers, for example ^{12}C, ^{13}C and ^{14}C. Carbon mainly consists of ^{12}C, with *small* amounts of ^{13}C and ^{14}C. All these are isotopes, or atoms of the *same* element with *different* mass numbers.

(d) Ions

These are atoms or a group of atoms which have lost or gained electrons and are electrically charged (Section 4.3).

(e) Radioactivity

Some chemical elements or isotopes are called *radioisotopes* and are *unstable*. This means their atoms disintegrate or undergo *nuclear fission*, and produce *three* kinds of radiation:

(i) *Alpha- or α-rays* are large particles consisting of two protons and two neutrons, and are unable to pass through thick paper.

(ii) *Beta- or β-rays* are high-speed electrons and can pass through thin sheets of aluminium.

(iii) *Gamma- or γ-rays* are part of the electromagnetic spectrum and are able to pass through fairly thick sheets of lead and penetrate the human body completely.

Since all these rays are different forms of *energy*, they are also detectable by photographic films, or by means of Geiger counter instruments which record the radiation by a clicking *sound* or on a meter *scale*.

(f) Radiobiology

This is that study concerned with the *effects* of radiations of all kinds on living organisms.

Radioactive *tracing* is the use of radioisotopes, e.g. ^{14}C, ^{42}K, ^{15}N, as components of *labelled compounds.* For example, carbon dioxide, CO_2, can be formed from ^{14}C, and potassium chloride, KCl, from ^{42}K. The compound is fed to the animal, or provided in soil nutrients to the plant, and its course traced through the organism's body by the Geiger counters.

Autoradiographs are made by placing the cell or part of the organism on a photographic film. Alternatively, thin transverse *sections* are placed on the film. This is developed to show the *location* of radioactive isotopes in the organism.

5.14 QUESTIONS

1 Draw and describe experiments showing diffusion in air and in solutions. Explain the meaning of the terms 'diffusion' and 'diffusion gradient'.

2 Draw and describe the apparatus used to demonstrate osmosis through a semipermeable membrane (e.g. Visking tubing). Explain why differences in liquid levels occur when using water and sugar solution in this apparatus.

3 Describe how a beam of light can be separated into its component colours. How can some invisible light components beyond the red and violet colours be detected?

4 Describe *four* methods by means of which a hot body can lose heat? What method can be used to reduce heat loss?

Explain the relationship between the changing surface area and heat loss.

5 The following data show body weight and body surface area for an adult and children. Calculate the ratio of surface area to body weight in each case, and indicate who would suffer the greatest heat loss from the unclothed body.

Person	*Body weight* (kg)	*Body surface area* (m^2)
Newborn baby	3.5	0.20
Two-year-old	12.5	0.55
Man	75.0	1.88

PART II

LIFE PROCESSES

CHAPTER 6

PLANT NUTRITION

6.1 NUTRITION

Nutrition is concerned with processes by which living organisms make or obtain inorganic or organic chemical compounds for the purpose of *energy* release, *growth*, *repair* and *secretion* production. Living organisms are either food *producers* or *consumers*.

Food producers include all green plants containing *chlorophyll* pigments and certain bacteria which are able to *synthesise* or make their own *organic* food materials from simpler inorganic compounds. Food producers are called *autotrophic* or self-feeding organisms.

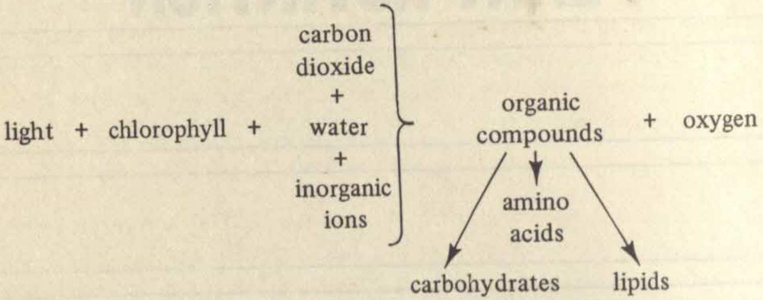
Food consumers include all animals, fungi and most bacteria which need a supply of ready-made organic and inorganic compounds. This food is obtained either directly or indirectly from the food producers.

6.2 PHOTOSYNTHESIS

Photosynthesis is the method of nutrition, or anabolic food synthesis of organic compounds from simple inorganic compounds, which occurs in *chlorophyll*-containing green plants using *light* energy. The method of nutrition is also called *holophytic* or green-plant nutrition.

Photosynthesis is a process of producing organic *food* materials, mainly carbohydrates, amino acids and lipids. The *raw materials* are water, carbon dioxide and inorganic salts or ions. *Energy* to drive the process is absorbed as light energy by the chloroplast *pigments*. The important *byproduct* of photosynthesis is *oxygen* as a gas.

Photosynthesis can be summarised as follows:


light + chlorophyll +
carbon dioxide + water + inorganic ions
organic compounds + oxygen
amino acids
carbohydrates
lipids

The following chemical equation summarises the process:

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2\uparrow$$

(a) Requirements for photosynthesis

Experiments are performed showing that photosynthesis can only occur if (a) chlorophyll pigments, (b) carbon dioxide, (c) water, (d) light, (e) inorganic mineral ions and (f) a suitable temperature are all present.

The *evidence* that photosynthesis *has* occurred is seen in the formation of either *oxygen* gas or the *organic* compound. The organic compound which can be most *easily* detected chemically is the carbohydrate, *starch*. Starch is by no means the only carbohydrate to be formed during photosynthesis.

Experiment 6.1 ***testing leaves for starch***

Procedure

(i) Immerse either a whole leaf or discs punched out of a leaf with a large-diameter cork borer in boiling water for half a minute.
(ii) Then immerse in hot ethanol (methylated spirits) in a heated water bath. (CARE: extinguish all naked flames.) Afterwards dip the specimen into hot water.
(iii) Treat the specimen with iodine solution and rinse away the excess in cold water.

Observations

Boiling water destroys the leaf cell semipermeability, allowing ethanol to penetrate and *dissolve* the green chlorophyll pigments from the chloroplasts. The colourless leaf then stains purple-black showing the presence of *starch* granules.

Destarching plants

Experiments are performed using potted flowering plants such as *Pelargoniums* (geraniums) and *Tradescantia*. Any starch present in them is removed by keeping the plants in total *darkness* for 48 h before any experiment. Any starch found in a leaf after an experiment must have formed under the experimental conditions.

(i) *Carbon dioxide*

Carbon dioxide is present in air to the extent of 0.03%, and enters the leaf by *diffusion*. Carbon dioxide is also formed in respiring cells.

Submerged *aquatic* plants obtain carbon dioxide from the surrounding water, the gas being readily dissolved from the air, or respiring aquatic animals.

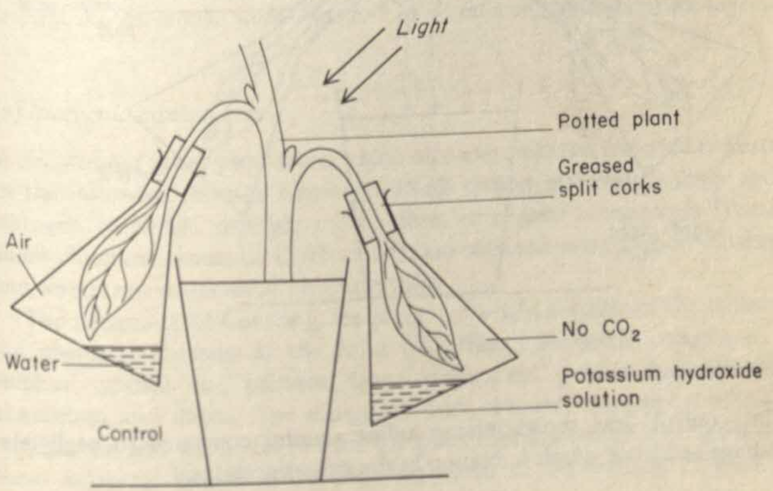
Experiment 6.2 *to show that carbon dioxide is required for photosynthesis* (Fig. 6.1)

Procedure

(i) Enclose two leaves of a destarched potted plant separately in supported flasks. One leaf is in an atmosphere *free* of carbon dioxide, the gas being absorbed by either soda lime or potassium hydroxide solution. The 'control' contains air.

(ii) The leaves are tested for starch after being placed in the light for at least 6 h.

fig 6.1 *to show that carbon dioxide is needed in photosynthesis*



Observations

The leaf in CO_2-*free* air forms very little starch compared to the control, as shown by the intensity of iodine staining due to starch formation in the 'control' leaf.

(ii) *Light*

Between 1 and 5% of the total light energy falling on a green plant is used in photosynthesis

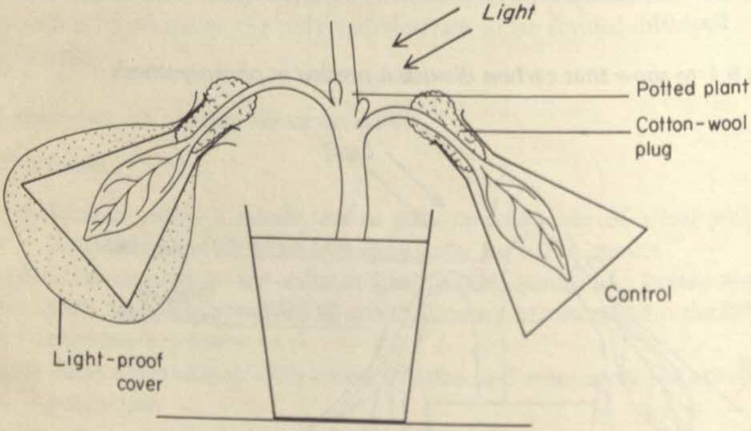
Experiment 6.3 *to show that light is required for photosynthesis* (Fig. 6.2)

Procedure

(i) Enclose two leaves of a destarched potted plant separately in a supported flask blacked out with lightproof material, and in a supported flask (the 'control') *without* black-out. Lightly stopper each flask with cotton-wool plugs.

(ii) The leaves are starch tested after exposure of the plant to light for 3 to 6 h.

fig 6.2 *to show that light is needed in photosynthesis*



Observations

The 'control' leaf shows intense iodine staining compared to negligible staining and little starch formation in the experimental leaf.

(iii) *Chlorophyll pigments*

Green plants have the *chloroplast* organelles mainly in the leaves and in green stems. There are four main pigments in the chloroplast: *green* chlorophyll 'a' and 'b', *orange* carotene and *yellow* xanthophyll.

Tradescantia, *Pelargonium*, ivy and maple are plants with the chlorophyll pigments being present in certain leaf areas and absent from others. Such leaves are *variegated*.

Experiment 6.4 *to show that chlorophyll pigments are required for photosynthesis*

Procedure

(i) Trace by means of tracing paper the distribution of the green and white areas of any *variegated* leaf which has been exposed to sunlight.

(ii) Starch test and compare the iodine staining areas with the original leaf tracing.

Observations

Starch forms only in the chlorophyll pigment areas of variegated leaves.

(iv) *Water*

Only 1% of the total water entering the plant by absorption through the root hairs and reaching the leaves by the transpiration stream is used as a raw material for photosynthesis. Another source of water is the product of respiration, *metabolic water*, formed in all cells containing mitochondria.

(v) *Inorganic mineral ions*

A *dehydrated* green plant from which all water has been removed consists of the following *chemical elements*: 95.6% carbon, hydrogen, oxygen and nitrogen combined together in the form of *organic compounds*. These three chemical elements, C, H and O, are obtained from carbon dioxide and water, raw materials of photosynthesis.

The remaining 4.4% of the green plant dry weight consists of the following chemical elements in the form of different *inorganic compounds*: sulphur, phosphorus, calcium, iron, magnesium, potassium, chlorine, aluminium and silicon. The *source* of these chemical elements is soluble salts in the soil water, taken into the plant root system as *ions*. Each of these inorganic *ions* have different functions in the process of photosynthesis.

Experiment 6.5 *to show the importance of certain chemical elements in green plants* (Fig. 6.3)

Procedure

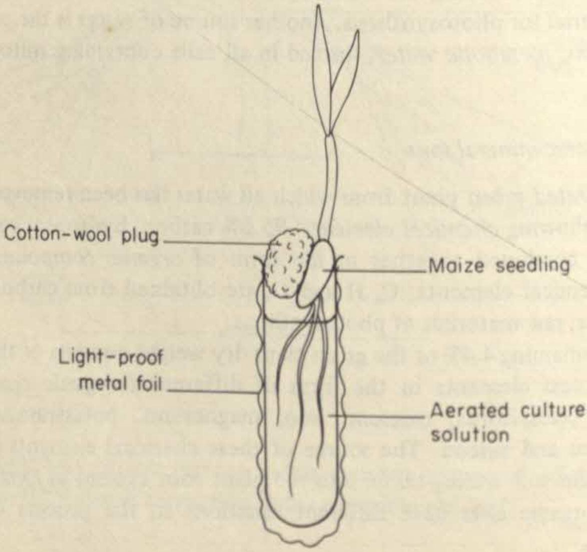
(i) Green plants can be grown in water or sand *culture solutions*; these are solutions containing the essential chemical elements in the form of soluble inorganic salts needed for metabolism of healthy plants. Solutions containing all the elements are *complete* culture solutions. Solutions with *one* missing chemical element are *incomplete* culture solutions; these may *lack* nitrogen, calcium, sodium, magnesium, iron, phosphorus or potassium ions.

(ii) A 'control' solution or complete culture is prepared, and seven other incomplete cultures. Each solution and the containing tube is heat-*sterilised* in a pressure cooker.

(iii) Fourteen-day-old seedlings of maize, wheat, barley or oats are grown, allowing them to consume their seed food reserves. The seedlings are washed in cold water and supported with their roots dipping into the culture solution. Periodically the solution is *aerated* by blowing in a current of *sterile* air.

(iv) The outer surface of the cultured tubes is made *lightproof*, and the tubes with their seedlings maintained together for three weeks at a *constant temperature* of 30°C. The solutions are periodically topped up.

fig 6.3 *water culture experiment to find the mineral ion requirements of a green plant*



Observations

Aeration of the culture solution is needed for root hairs to respire. *Sterilisation* is to prevent growth of microbes, and *lightproofing* prevents algae growth.

Differences between the seedlings grown in the 'control' and incomplete cultures are to be seen as intensity of *green* chlorophyll colour, size of leaves and plants, root growth and general 'healthy' appearance.

(b) Macro- and micronutrients

Apart from carbon, hydrogen and oxygen, a plant requires seven *macronutrient* ions, calcium, potassium, iron, magnesium, nitrogen (nitrate), phosphorus (phosphate) and sulphur (sulphate). In addition, inorganic chemical elements are needed in very small amounts called *micronutrients* or trace elements; these include the following as ions: boron, manganese, copper and zinc.

Table 6.1 summarises the more important nutrients and their use in the green plant. These chemical elements will be provided in the soil from:

(i) natural soil mineral components; and
(ii) added chemical artificial or natural *fertilisers*.

Table 6.1 *plant mineral nutrients*

Element and source	*Use in plant*	*Effect of deficiency*
Nitrogen (N): nitrates and ammonia	To form amino acids, proteins, nucleic acids and chlorophyll	Chlorosis – yellowing of leaves. Poor growth
Sulphur (S): sulphates	To form certain amino acids and hence proteins	Chlorosis of young leaves and excessive root growth
Phosphorus (P): phosphates	To form ATP for respiration and photosynthesis; also to form nucleic acids	Poor growth due to lack of energy
Potassium (K): potassium salt fertiliser	Helps protein and chlorophyll formation, and resistance to disease	Yellowing and abnormal leaf shape
Calcium (Ca): lime	Cell wall cement in middle lamella between cells	Abnormal leaf shape, stunted plants and poor root growth
Magnesium (Mg): as salts in fertiliser	Forms centre of chlorophyll molecule	Chlorosis of older leaves
Iron (Fe): fertiliser salts	Essential for forming chlorophyll	Chlorosis of young leaves

6.3 THE RATE OF PHOTOSYNTHESIS

Two methods can be used to measure the *rate* of photosynthesis.

(a) Dry weight method

Part of a living green plant is removed and dried to constant weight at 110°C. After a certain time lapse another leaf sample from the same plant is dried in the same way and the *percentage increase* in weight determined.

(b) Oxygen production

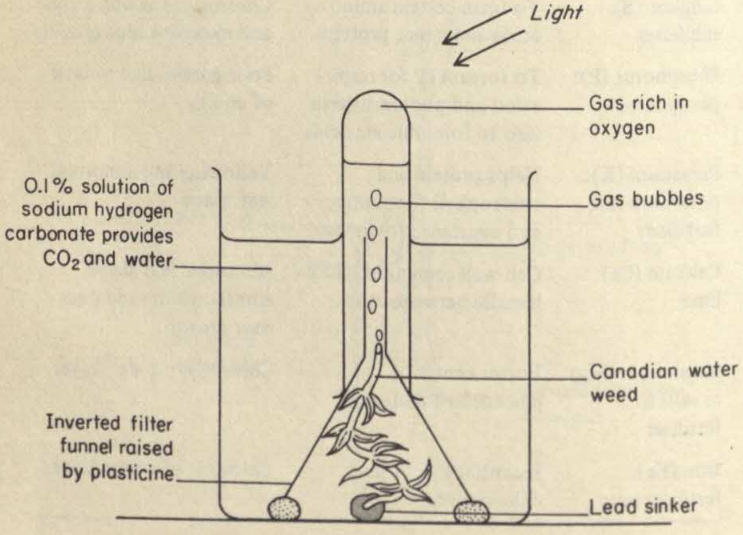
This is the simpler method suitable for *submerged* aquatic plants. It involves counting the *number* of oxygen bubbles issuing from the cut end of an *Elodea* Canadian pondweed plant, kept at a constant temperature and evenly illuminated.

Experiment 6.6 *to show oxygen production and to measure the rate of photosynthesis of an aquatic plant* (Fig. 6.4)

Procedure

(i) Set up a newly cut fresh portion of *Elodea* beneath an inverted glass filter funnel in a solution of 0.1% sodium hydrogen carbonate. Arrange the cut stem end into the filter funnel stem-end. Invert a test tube full of 0.1% sodium hydrogen carbonate solution over the filter funnel stem. This solution provides the plant with carbon dioxide and water.

fig 6.4 *to show gas production in photosynthesis using Canadian pond-weed,* Elodea canadensis


Light
Gas rich in oxygen
0.1% solution of sodium hydrogen carbonate provides CO_2 and water
Gas bubbles
Canadian water weed
Inverted filter funnel raised by plasticine
Lead sinker

(ii) Maintain the whole apparatus at 30°C in a thermostatically controlled water bath in a well lighted position for a few days.

(iii) When the bubble production is established, carefully count the number of bubbles produced over a certain time.

(iv) A 'control' experiment is set up, keeping the apparatus in continual darkness.

(v) Allow a sufficiently large sample of gas to collect in the inverted tube. The chemical composition of the gas is found by inserting a glowing wood splint; when it relights, it shows the *presence* of oxygen. The gas can be analysed using a syringe and alkaline pyrogallol (benzene-1,2,3-triol) solution. This will indicate that the gas contains *more* oxygen than a similar volume of room air.

Observations

The gas produced in photosynthesis is not *pure* oxygen but a *mixture* of gases, mainly oxygen, nitrogen and carbon dioxide in lesser proportion than in room air.

The *rate* of photosynthesis is indicated as the *number* of oxygen bubbles produced per minute from a *unit weight* of the plant.

(c) External factors affecting photosynthesis

The *Elodea* respiration rate apparatus can be used to determine the effect of changing *one* external factor, whilst others remain *constant*.

(i) *Light intensity*

An electric lamp (40 W) is used to illuminate the apparatus at different *distances* and consequently at different light *intensity*. The temperature is maintained at 30°C and the 0.1% solution of sodium hydrogen carbonate used. A glass tank full of water is placed between the apparatus and the lamp to act as a heat shield.

Light intensity is one of the *main* external factors affecting the rate of respiration, which is seen to *increase* up to a certain light intensity value, above which there is *no* further increase.

(ii) *Carbon dioxide*

The *concentration* of carbon dioxide is varied by using different solutions of sodium hydrogen carbonate which provide from 0.01 to 1.0% of CO_2. Distilled water is used to provide a zero concentration. Both the temperature and light intensity are maintained constant throughout the experiments. The *rate* of photosynthesis increases up to a certain concentration of CO_2, above which there is no further increase.

(iii) *Temperature*

Provided the light and CO_2 concentrations are maintained *constant*, the effect of varying the temperature by means of a thermostatically controlled water bath can be shown to affect the photosynthesis rate.

With increasing temperature the rate rises, to reach an *optimum* at 35°C, after which the rate falls and stops above 40°C when *enzymes* are destroyed. A rise in temperature of 10°C below the optimum temperature *doubles* the rate of photosynthesis.

(d) Limiting factors

When a process depends on more than *one* variable external factor, the *rate* of the process will depend on the factor which is in *shortest* supply.

The main variable external factors in photosynthesis are: carbon dioxide concentration, light intensity, temperature, water, and certain mineral ions. If all but *one* are present in excess, the *rate* of photosynthesis will be affected. For example, too *low* a light intensity in the presence of an excess of the other factors *slows* the rate. This will remain until the light intensity is increased to its *optimum* level.

(e) Glasshouse crops

Well watered lettuce plants growing in *brightly illuminated* greenhouses with *ample* supply of soil nutrients will experience a *limiting factor* in the amount of carbon dioxide present in the air at 0.03%. Thus all factors for photosynthesis are in *excess* except the supply of CO_2. This can be *increased* by installing gas burners which produce carbon dioxide as a product of combustion; in this way the limiting factor is now raised from 0.03 to 0.1%, and also allows an incidental increase in temperature. The rate of photosynthesis *increases*, causing an increase in size and dry weight of lettuce plants and an overall increase in crop production.

6.4 THE LEAF IN PHOTOSYNTHESIS

(a) Leaf external structure

A leaf consists of a *lamina* or leaf blade, which is broad in dicotyledon plants and narrow in monocotyledon plants such as grasses. Mosses have very *simple* leaves.

The *petiole* or leaf stalk may be present, as in most broad-leaved plants, to attach the leaf to the stem at a point called the *node*. The *midrib* is an extension of the petiole, forming branch veins and a *network* of small veins in broad leaves (Fig. 6.5), or a *parallel* arrangement of veins in monocotyledon plants.

The angle formed between the upper side of a leaf and the stem is called the *axil* and a *bud* is positioned there.

(b) Leaf functions

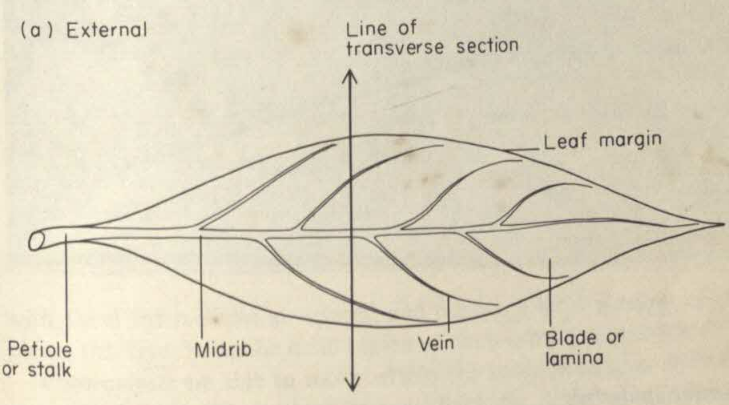
Leaves have several functions: photosynthesis, respiration (see Section 10.3), transpiration (see Section 9.4) and temporary storage of *starch*, and can be a means of reproduction by leaf cuttings.

(c) Internal structure

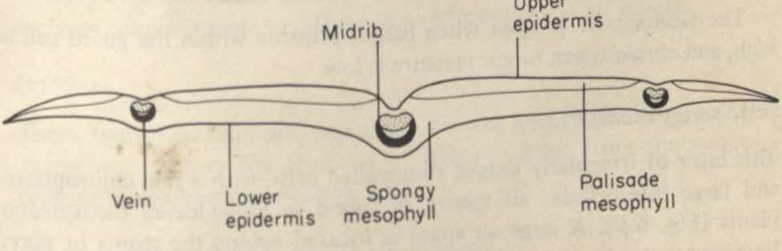
A typical flowering plant leaf has three main layers, upper and lower *epidermis*, with middle layer or *mesophyll* (Fig. 6.5).

fig 6.5 *the (a) external and (b) internal structure of a dicotyledon leaf, the privet,* Ligustrum *sp.*

(a) External



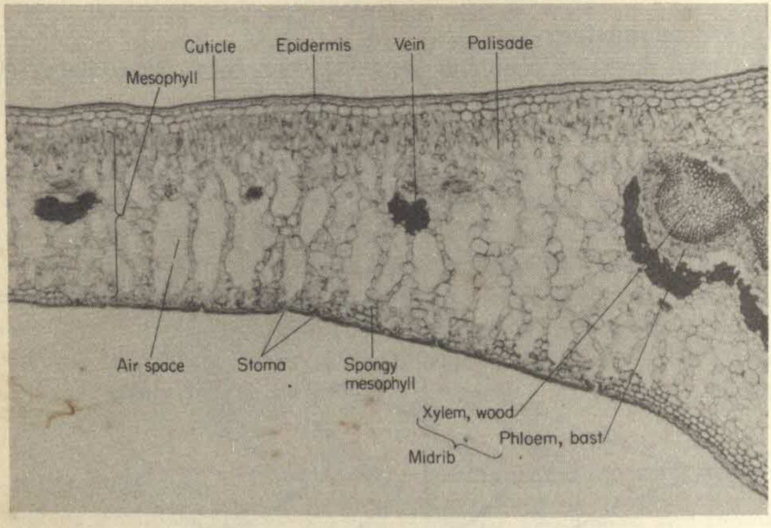
(b) Internal



(i) *Upper epidermis*

This is a single transparent layer of cells, each with a nucleus and clear cytoplasm, completely covering and protecting the leaf lamina upper surface (Plate 6.1). A waxy cuticle serves to prevent *water loss* by evaporation.

plate 6.1 *a photomicrograph showing the structure of a holly leaf,* Ilex *sp. seen in transverse section (Griffin Biological Laboratories)*



(ii) *Lower epidermis*

This is similar to the upper epidermis, differing by having a great number of pores or *stomata* each composed of two *guard cells* containing a nucleus and a few chloroplasts. The cell wall of the guard cell adjacent to the *stoma* or pore is thickened.

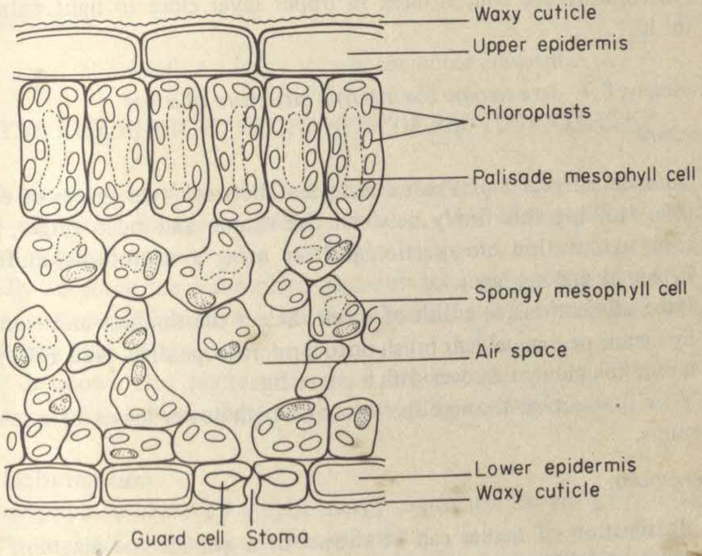
The stoma pore is *open* when turgor pressure within the guard cell is high, and *closed* when turgor pressure is low.

(iii) *Spongy mesophyll*

This layer of irregularly shaped thin-walled cells, with a *few* chloroplasts, and large intercellular air spaces, is found in broad-leaved dicotyledon plants (Fig. 6.6). A large air space is located behind the stoma or pore. Excessive water loss is *partly* reduced by the stomata being positioned on a leaf *lower* surface away from the direct rays of the Sun.

(iv) *Palisade mesophyll*

This layer beneath the upper epidermis receives the maximum amount of light from the Sun's rays. The cells are cylindrically shaped, thin-walled fig 6.6 *detailed structure of a dicotyledon leaf*



with small intercellular air spaces, and contain a large number of chloroplasts, this layer being the main region of photosynthesis in the leaf.

Chloroplasts are able to move within the palisade cells by cytoplasmic streaming seen in *Elodea* leaf. In poor light, the *disc*-shaped chloroplasts arrange themselves *sideways* on to the light near the top of the palisade cell. In bright light the chloroplasts are arranged *edge*- or *end-on* near the sides and base of the palisade cells.

Both types of cell in the mesophyll have films of water on their outer surfaces, allowing gases to diffuse to and from the leaf air spaces.

(v) *Veins*

These transport water and inorganic mineral ions from the roots in the *xylem* and remove the products of photosynthesis from the mesophyll cells by the *phloem* (see Section 3.9).

(d) Adaptations of the leaf to photosynthesis

(i) Large *surface area* for maximum light absorption.
(ii) Leaf *arrangement* at right-angles to the light source, and by maximum display in a leaf *mosaic* pattern.
(iii) Rapid *transport* to and from mesophyll cells by extensive vein system.
(iv) Numerous *stomata* allow rapid exchange of gases, oxygen and carbon dioxide.

(v) *Thinness* of the leaf reduces distances between cells, thus facilitating rapid transport. Thin cell walls of mesophyll allow rapid diffusion.

(vi) *Chloroplasts* are concentrated in upper layer close to light entering the leaf.

Experiment 6.7 *to examine the internal structure of a leaf*

Procedure

(i) Sandwich a privet or *Tradescantia* leaf between two pieces of elder pith. Holding this firmly between the thumb and index finger, proceed to cut thin cross-sectional slices using a microtome knife or flat-sided shaving razor.

(ii) Place all sections in a dish of water. Select the thinnest and transfer by means of a camel-hair brush onto a microscope slide. Add a drop of iodine solution, and cover with a coverslip.

(iii) View the section through the low- and high-power lenses of a microscope.

Observations

The distribution of tissues can be shown in a general line diagram. The tissues are identified by reference to Fig. 6.6. Note the location of starch granules in the palisade mesophyll cells.

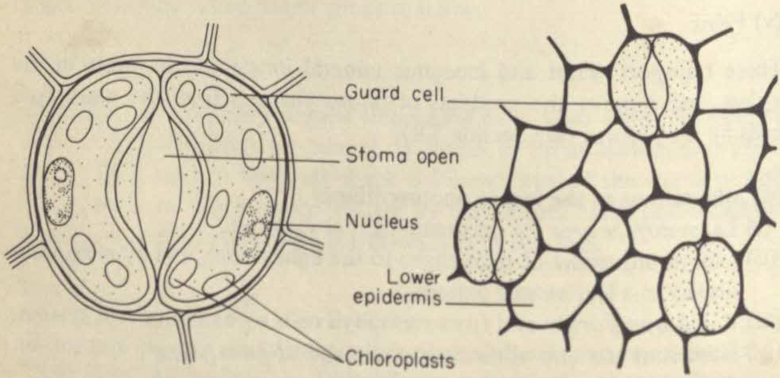
Experiment 6.8 *to examine leaf stomata* (Fig. 6.7)

Procedure

(i) Peel a portion of the lower and upper epidermis from broad bean or other broad-leaved plants.

(ii) Place on a microscope slide and add a drop of iodine solution.

fig 6.7 *air pores or stomata of a dicotyledon leaf seen in surface view*



(iii) View the epidermis through the microscope, and make a count of stomata to be seen in the lower and upper epidermis.

Observations

Few if any guard cells are to be seen in the upper epidermis.

6.5 THE BIOCHEMICAL MECHANISM OF PHOTOSYNTHESIS

Each disc-shaped chloroplast *outer membrane* provides a large surface area compared to the organelle's volume. This allows carbon dioxide, water vapour, mineral ions and light energy to enter the chloroplast rapidly to reach the chlorophyll pigments arranged on the *internal membrane* surface. *Chlorophyll 'a'* is the pigment having the maximum ability to absorb light energy.

It is known that photosynthesis is a *two*-stage process. One reaction requires *light*, and the other can proceed with or without light.

(a) Light reaction

Chlorophyll 'a' absorbs the light energy to produce the *energy-rich* organic compound ATP (adenosine triphosphate).

Some energy absorbed by chlorophyll 'a' is used to *split* up water into hydrogen *atoms* and oxygen molecules which form oxygen *gas*:

$$2H_2O \longrightarrow \underset{\text{hydrogen } atoms}{4H} + \underset{\text{oxygen gas } molecule}{O_2}$$

(b) Dark reaction

This is a chemical reaction proceeding either in the dark or in the presence of light. The hydrogen *atoms* reduce or add on to the carbon dioxide, in the chemical change called *reduction*. This change occurs using the ATP energy formed in (a) above.

This chemical change is controlled by *enzymes*, many of which contain the chemical element *sulphur*; it is affected by changes in *temperature*.

An organic *intermediate* compound called *triose phosphate*, having three carbon atoms, is the first carbohydrate compound formed in the dark reaction of photosynthesis. Phosphate ions provided by soil water are required in the photosynthesis to form the triose phosphate.

(c) Products of photosynthesis

Apart from *oxygen* gas, the following are the main products of photosynthesis formed by different metabolic *pathways* from the compound *triose phosphate* which contains three carbon atoms:

(i) *Carbohydrates*

Triose phosphate is readily changed by *enzymes* from a three-carbon compound into a six-carbon compound, *glucose*, $C_6H_{12}O_6$, and then rapidly into *starch* to be stored for a *short* period in the leaf.

At night, starch is changed by enzyme action into *sucrose* and is transported in this form throughout the plant. If not used in cell respiration, it is used to build *cellulose* cell walls, or is stored as *starch* granules in storage organ cells.

Experiment 6.9 *to show glucose in plant tissue*

Procedure

(i) Grind green onion, iris, or hyacinth leaves with clean silver sand in a mortar and pestle. Drain off and filter the juices.
(ii) Test the juice filtrate with a 'Clinistix' reagent strip or with Fehling's or Benedict's solution for the presence of reducing sugars (see Experiment 4.5).

Observations

Glucose, a reducing sugar, is present in some green plant tissues.

(ii) *Amino acids*

Glucose present in *growing regions* of roots and stems is changed by enzyme action and combination with nitrogen from ammonium and nitrate ions to form amino acids. These amino acids are made into proteins by means of RNA (ribonucleic acid).

6.6 QUESTIONS

1 Draw a labelled diagram showing the detailed structure of a portion of a flowering plant leaf in cross-section. What are the functions of each labelled part of the diagram?

2 Name the *form* and *source* from which a green plant obtains the following chemical elements: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium and magnesium. Describe the function and effect of a deficiency of *three* of these elements in a green plant.

3 What is photosynthesis? Describe the conditions necessary for it to occur. How is a green leaf tested for starch? How is a green plant 'destarched'?

4 Describe controlled experiments showing how *two* certain conditions are necessary for photosynthesis to occur.

5 Describe controlled experiments which show the influence of changing temperature and light intensity on the rate of photosynthesis. What is meant by the limiting factor on the rate of photosynthesis?

6 Why does the following chemical equation provide insufficient information concerning the process and mechanism of photosynthesis:

$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} \longrightarrow \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

CHAPTER 7

ANIMAL NUTRITION

7.1 TYPES OF NUTRITION

Animals are *heterotrophic* organisms requiring ready-made organic and inorganic compounds as food. This is taken into the body, broken down, absorbed and used by the animal's protoplasm. *Heterotrophic animals* are of three main kinds:

(i) *Holozoic* animals feed in a typical animal-like way, by eating other organisms or foods made by them.

(ii) *Saprozoites* are animals and *saprophytes* are plants (fungi) which feed on dead and decaying matter.

(iii) *Parasites* are organisms obtaining their food from another living organism called the *host*.

7.2 PHYSICAL AND CHEMICAL FOOD CHANGES

Food undergoes two main changes during the feeding processes of animals. *Physical* changes involve the physical form or condition of the food, and *chemical* changes involve the food chemical composition. Table 7.1 is a summary of physical and chemical food changes.

(a) Digestive enzymes

Enzymes are usually *specific*, one particular enzyme catalysing the hydrolysis of one particular compound. There are four main groups of enzymes:

(i) *Glycosidases or carbohydrases*

These include those enzymes able to digest or hydrolyse *carbohydrates* and finally form *monosaccharides* such as glucose:

$$\text{carbohydrates} \xrightarrow[\text{carbohydrases}]{\text{glycosidases}} \text{monosaccharides}$$

Table 7.1 *summary of physical and chemical food changes*

	Physical changes		*Chemical changes*
1	*Surface area* of solid food *increased* by cutting, tearing, grinding, and biting. Food preparation, chopping, crushing and milling. Teeth or gizzard action.	1	*Enzymes* for *intracellular* digestion within cells, and extracellular digestion outside cells.
2	*Blending* with digestive juices in mouth, chewing and stomach churning.	2	*Hydrolysis*: chemical action with water catalysed by enzymes.
3	*Melting* of solid lipid fats at 39°C.	3	*Neutralisation* for control of pH in different gut regions.
4	*Dissolving* of soluble nutrients in aqueous digestive juices.	4	*Hormones* to cause secretion of digestive juices.
5	*Emulsification* of lipids by bile emulsifier agents.	5	*Cooking* alters food chemically. (a) Starch granules swell and burst to form dextrins. (b) Cellulose broken down and cell contents released. (c) Hydrolysis in moist cooking converts proteins into amino acids, starches into simple sugars.
6	*Lubrication* of food in gut by mucin.		
7	*Mechanical* stimulation by roughage fibre causes peristalsis in gut wall and secretion of mucus.		

(ii) *Proteases*

Proteases or proteolytic enzymes digest or hydrolyse proteins and finally form *amino acids*:

$$\text{proteins} \xrightarrow{\text{proteases}} \text{amino acids}$$

(iii) *Lipases*

These are the enzymes which split lipids into fatty or alkanoic acids, and glycerine (propanetriol):

$$\begin{matrix}\text{lipids} \\ \text{(oils and fats)}\end{matrix} \xrightarrow{\text{lipases}} \begin{matrix}\text{fatty} \\ \text{(alkanoic)} \\ \text{acids}\end{matrix} + \begin{matrix}\text{glycerine} \\ \text{(propanetriol)}\end{matrix}$$

(iv) *Nucleases*

These are necessary to digest the nucleic acids RNA and DNA which are present in all cells, to form phosphate, ribose sugar and nitrogen bases:

$$\text{nucleic acids} \xrightarrow{\text{nucleases}} \text{phosphate} + \text{ribose} + \text{nitrogen bases}$$

7.3 HETEROTROPHIC NUTRITION

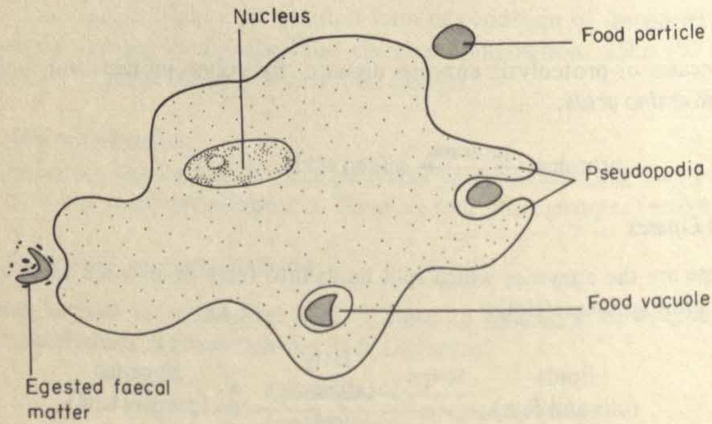
The processes involved in feeding or nutrition of heterotrophic animals are:

(i) *ingestion*, the *intake* of complex organic food into the body;
(ii) *digestion*, the *breakdown* of large molecules in insoluble organic compounds into smaller molecules of soluble food *nutrients*, by means of hydrolytic enzymes;
(iii) *absorption*, the *uptake* of food nutrients into living cells;
(iv) *assimilation*, the *usage* of food nutrients within the living organisms, a process which follows *transport* of food nutrients;
(v) *egestion*, the *elimination* of indigestible food waste from the organism.

(a) *Amoeba* nutrition – intracellular digestion

Amoeba is an *omnivorous* animal feeding on comparatively large food particles such as algae and bacteria (Fig. 7.1).

fig 7.1 *ingestion and egestion in* Amoeba *sp.*



Ingestion occurs by *enclosing* the food particle by pseudopodia by a process called *phagocytosis*. A food vacuole is formed.

Digestion of food occurs *within* the food vacuole by means of digestive juices secreted from the cytoplasm. This digestion process occurs *inside* the cell and is *intracellular* digestion.

Egestion of food remains occurs by a reverse process to ingestion, the food vacuole discharging its contents into the surrounding water.

Absorption of the digested food occurs by diffusion and possibly *active transport* into the surrounding cytoplasm aided by energy provided by numerous mitochondria close to the food vacuole.

(b) *Hydra* nutrition – intracellular and extracellular digestion

Hydra is a *carnivorous* animal feeding on small water fleas, *Daphnia*.

Ingestion is by means of the captive water flea being stung by the tentacle sting cells, and moved towards the *mouth* opening into the *gut* or *enteron* cavity. The *gut* is a term used for the alimentary canal.

Digestion is by means of: (a) gland cells in the endoderm secreting digestive enzymes into the gut – this breakdown of food *outside* the cells is called *extracellular* digestion; (b) small food particles are ingested by endoderm cells by *phagocytosis* – digestion then occurs *intracellularly* inside the endoderm cell.

Egestion of indigestible material takes place through the mouth.

Absorption is by diffusion and active transport from the enteron or gut and within the endoderm.

(c) Earthworm nutrition – extracellular digestion

The surface soil contains plant and animal debris, and provides a partly *omnivorous* and *saprozoic* form of nutrition in that it also contains dead and decaying matter.

Ingestion is by soil taken into the *mouth*, aided by muscle action of the pharynx. The gut is tubular with a *crop* where *extracellular* digestion occurs, followed by a *gizzard* serving to crush the soil.

Egestion of the fine *wormcast* is by the terminal *anus*.

7.4 LIQUID FEEDERS

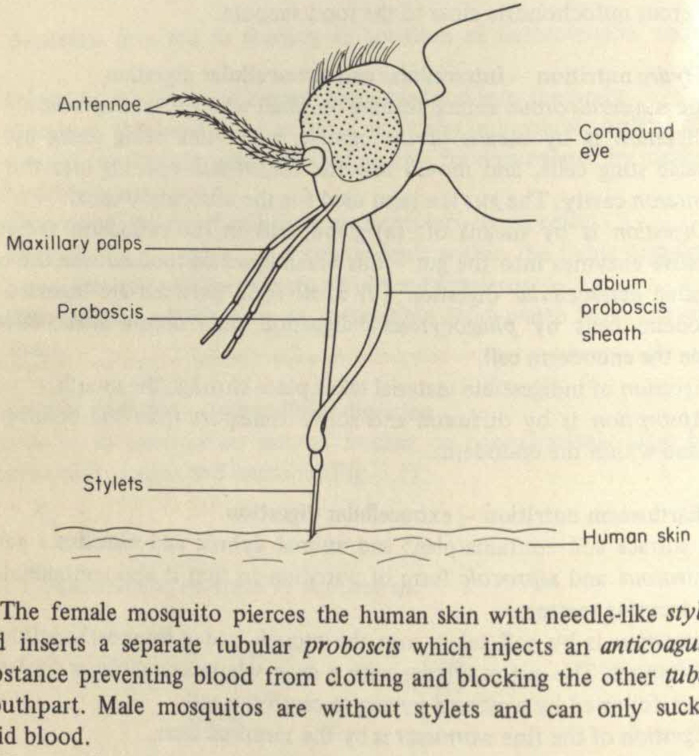
(a) Endoparasites

The tapeworm, *Taenia solium*, is an *endoparasite* found inside the small intestine of man, attached to the wall by a head or *scolex* (Fig. 2.11). The long flattened tape-like body has a large *surface area* to absorb the digested food which bathes the body. No digestion is required as it is ready for absorption. The tapeworm is protected from being digested itself by a thick *enzyme*-resistant *cuticle* or tegument.

(b) Ectoparasites

The *female* mosquito, *Anopheles* (Fig. 7.2), the greenfly, *Aphis*, and human flea, *Pulex irritans*, are all *ectoparasites*. They are insects with *mouthparts* which are modified for *piercing* and *sucking* fluid into their own gut.

fig 7.2 *the piercing and sucking mouthparts of a female mosquito,* Anopheles *sp.*



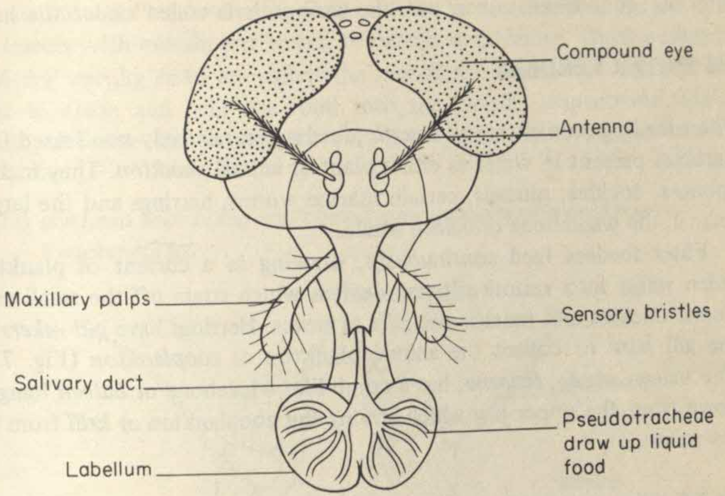
The female mosquito pierces the human skin with needle-like *stylets*, and inserts a separate tubular *proboscis* which injects an *anticoagulant* substance preventing blood from clotting and blocking the other *tubular* mouthpart. Male mosquitos are without stylets and can only suck up fluid blood.

Human fleas *pierce* and then suck up blood in a similar way to the mosquito using stylets which also function as a sucking tube.

Greenfly pierce the leaf epidermis by stylets and suck up food in solution by the tubular proboscis in contact with the leaf *vein* or mesophyll cells.

(c) Saprozoic animals

The housefly, *Musca domestica* (Fig. 7.3), is a *saprozoic* animal feeding mainly on dead and decaying material. It places its tubular mouthpart directly on solid or liquid material and then secretes a *saliva* fluid seen as fig 7.3 *the sucking mouthparts of a housefly,* Musca domestica

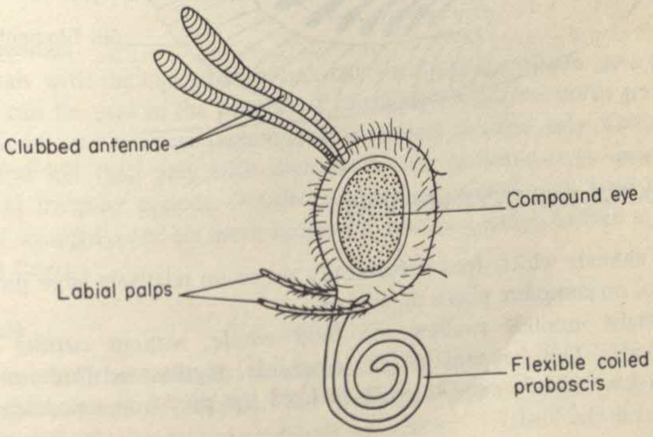


'fly spots', which externally digests the organic substances and then *dissolves* its soluble products. This solution enters the tubular proboscis partly by *capillary rise* and by *suction* into the gut. Alternatively, soluble foods are drawn into the gut directly as when a fly feeds on foul water or milk.

(d) Holozoic animals

The butterfly, *Pieris brassicae* (Fig. 7.4), feeds holozoically on the liquid *nectar*, a solution of sucrose, produced in insect-pollinated flowers. The

fig 7.4 *the sucking mouthparts of a butterfly,* Pieris *sp.*



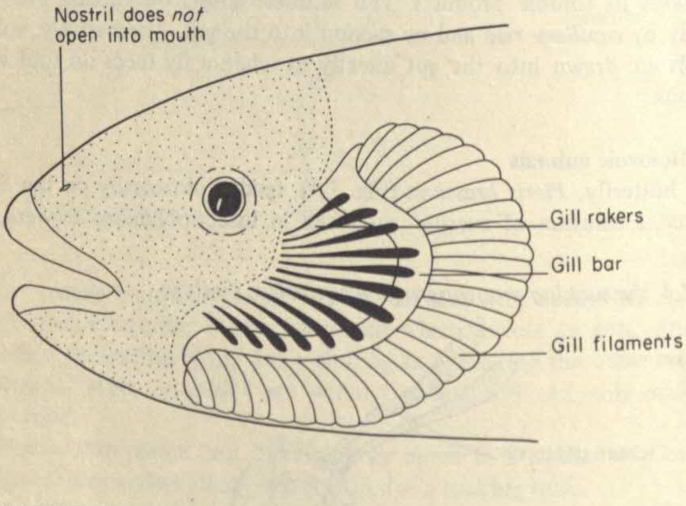
tubular mouthpart reaches into the flower and the nectar is sucked up into the gut. When not in use, the proboscis is coiled under the head.

7.5 FILTER FEEDERS

Filter-feeding animals are all *aquatic*, feeding on relatively *small*-sized food particles present in water as either plant or animal *plankton*. They include sponges, cockles, mussels, certain marine worms, herrings and the largest animal, the whalebone or baleen whale.

Filter feeders feed *continuously*, drawing in a current of plankton-laden water into various *filtering* devices which strain off the small organisms. Cockles and mussels use *gills* as sieves. Herrings have *gill rakers* on the gill *bars* to collect the animal plankton or *zooplankton* (Fig. 7.5). The baleen whale, *Balaena*, has a comb-like whalebone or *baleen* hanging down from the upper jaw which strains the zooplankton or *krill* from the sea water.

fig 7.5 *gill structure of a bony fish with gill operculum removed*



7.6 LARGE-PARTICLE FEEDERS

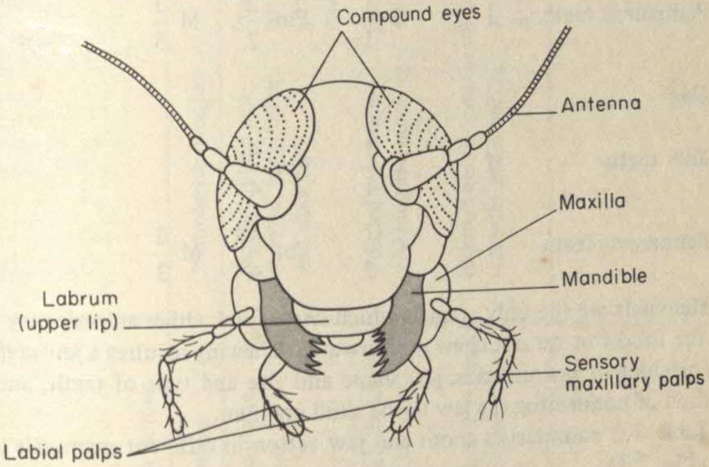
Land animals which feed holozoically do so on relatively *large* pieces of food or on *complete* plants or animals.

Certain animals swallow the food *whole*, without *cutting* it up previously. This happens in fish, amphibia, reptiles and birds, most of whom have *simple peg-like teeth* to hold the prey from escaping, or *no* teeth as in the birds.

(a) Insects

The cockroach, *Periplaneta* (Fig. 7.6), and the locust, *Schistocerca gregaria*, are insects with *mouthparts* suited to *cutting* or *crushing*. The mouthparts used for cutting food are called the *mandibles*, whilst the *maxillae* are used to crush and help the food into the mouth, respectively. Other mouthparts, the *labium* and *labrum*, have palps which have a sensory function.

fig 7.6 *the head with biting and chewing mouthparts of a cockroach,* Periplaneta *sp.*



The cockroach is an *omnivorous* insect, eating all types of food, whilst the locust is a *herbivorous* insect. Certain ground beetles are *carnivorous* insects.

(b) Mammals

Mammals with the exception of ant-eaters and certain whales have *teeth*, which can be used in the process of *obtaining* food. *Herbivores* graze on plant food, and consume large quantities almost continuously. *Carnivores* hold and kill their prey with their teeth, and consume large quantities often at *irregular* periods. *Omnivores*, having a mixed diet, tend to eat smaller quantities and are more successful animals, tending to feed at more regular times.

(i) *Teeth*

There are four main kinds of mammal teeth: (a) incisors, (b) canines, (c) premolars and (d) molars. The premolars and molars are at times indistinguishable; the molars are bigger and flatter.

Mammals have *two* sets of teeth; *milk* teeth are shed and replaced by *permanent* teeth.

A *dental formula* is used to show the number of teeth in *each side* of the upper and lower jaw in the mammal skull. The top line is for the upper jaw and the bottom line for the lower jaw.

Man

Milk teeth $I\,\frac{2}{2}\quad C\,\frac{1}{1}\quad Pm\,\frac{2}{2}$

Permanent teeth $I\,\frac{2}{2}\quad C\,\frac{1}{1}\quad Pm\,\frac{2}{2}\quad M\,\frac{3}{3}$

Dog

Milk teeth $I\,\frac{3}{3}\quad C\,\frac{1}{1}\quad Pm\,\frac{4}{4}$

Permanent teeth $I\,\frac{3}{3}\quad C\,\frac{1}{1}\quad Pm\,\frac{4}{4}\quad M\,\frac{2}{3}$

Mammals are the only animals which *chew* food. Other animals may *cut* up the food but do not chew it afterwards. Chewing requires a *jaw action*, the product of jaw muscles, jaw shape and size and type of teeth, and in method of connecting the jaw to the skull cranium.

Table 7.2 summarises tooth and jaw action in different mammals (see also Fig. 7.7).

(ii) *Tooth structure*

The main parts are the *crown* above the gum, and *root* below the gum in the jaw bone, or *mandible* (Fig. 7.8).

(1) Enamel

The tooth crown is covered with extremely hard *enamel*, a substance composed of keratin and hardened with minerals such as calcium and magnesium compounds.

The *ridges* seen in herbivore teeth are due to enamel being worn away in the *crosswise* chewing action.

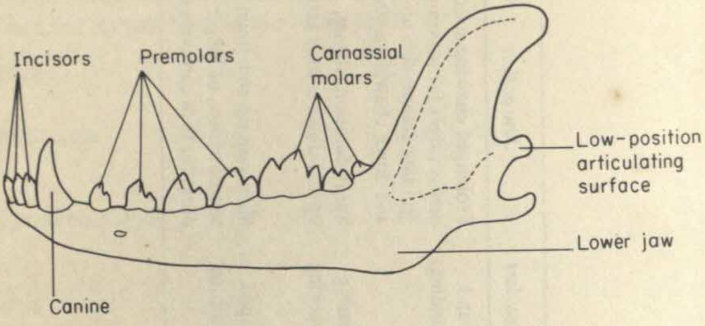
(2) Dentine

This is beneath the enamel layer and is a substance similar to but harder than bone. Fine canals connect it with the substance of the pulp cavity. Dentine is *exposed* in ridged herbivore teeth.

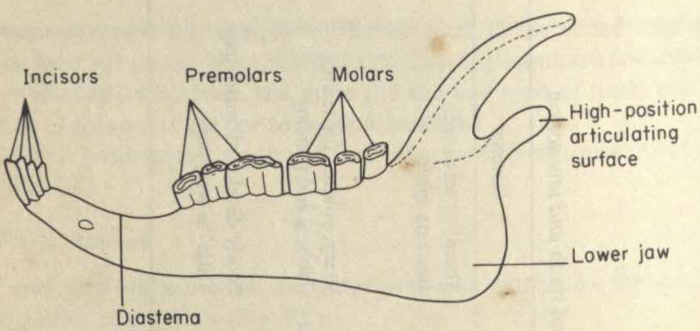
Table 7.2 *comparison of mammal teeth and jaw action*

	Incisors	*Canines*	*Premolars and molars*	*Jaw action*
Herbivore: sheep and horse	Cutting, sharp and chisel-like	Absent or small with diastema space	Similar, ridged and serrated, for grinding and chewing	Prolonged chewing action *across* ridges for maximum grinding action; also up-and-down chewing action
Carnivore: cat and dog	Small, pointed for picking up or flesh stripping	Sharp, pointed for tearing, stabbing and piercing	Pointed for shearing, crushing and cracking	Short-duration, strong, up-and-down scissor action
Omnivore: man and apes	Cutting and chisel-like	Poorly developed; males use 'fangs' as weapons	Pointed and cusped for chewing and crushing	Mainly an up-and-down scissor action, of longer duration than carnivores

fig 7.7 *lower jaws and type of teeth seen in a carnivore, dog,* Canis familiaris, *and herbivore, sheep,* Ovis *sp.*



(a) Dog



(b) Sheep

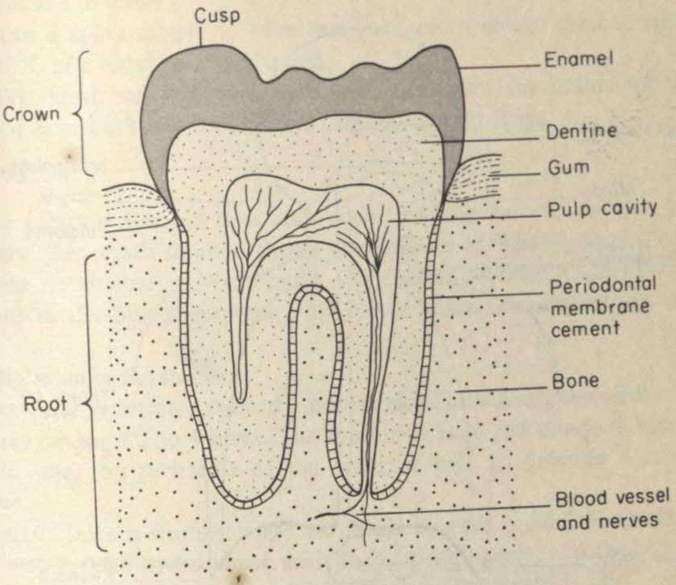
(3) Pulp cavity

This is the tooth centre containing blood capillary vessels and nerve endings which are sensitive to heat, cold and pain.

(4) Cement

The root is attached to the tooth socket by cement and the *periodontal* membrane. The fibres of this membrane allow the tooth to move slightly in the socket.

fig 7.8 *internal structure of a molar tooth seen in vertical section*



(5) Roots

Open roots are seen in continuously growing teeth, and these are present in the rodent and herbivore *dentition*, and teeth which are being *worn* away. *Closed* roots do not allow a good blood supply and are seen in teeth which grow to a certain size, as in carnivore and omnivore dentitions.

7.7 **DIGESTION IN MAN**

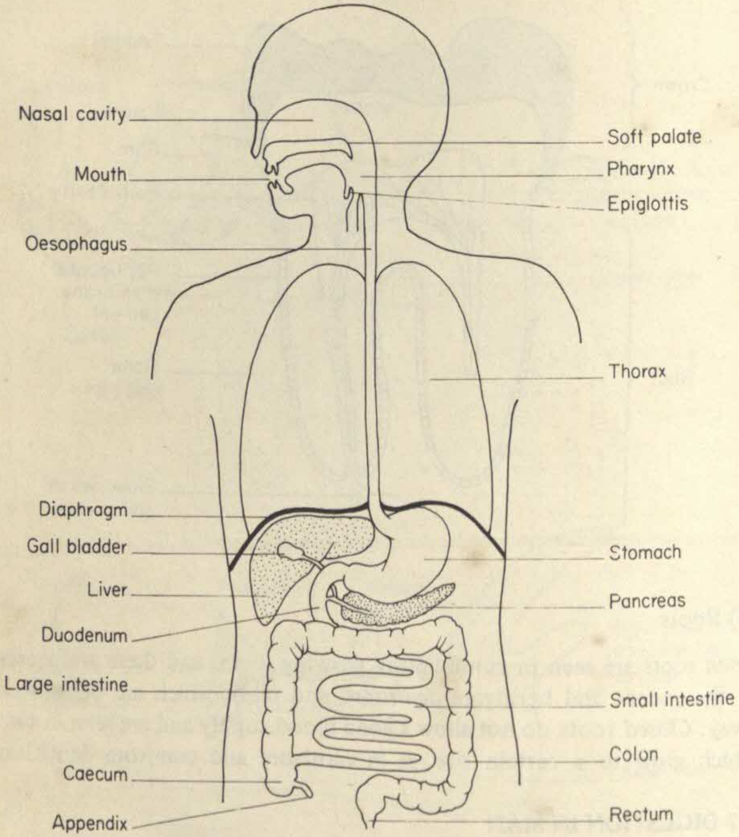
Man has a tubular *gut* 9 m in length extending from *mouth* to *anus* (Fig. 7.9). Digestion is *extracellular* within the gut cavity.

(a) Digestion in the mouth

Mastication or chewing of food blends the small food particles with the *saliva*, a secretion from three pairs of *salivary glands* located beneath the tongue, mandible and near to the ears.

Between 1 and 2 litres of saliva are produced daily as a watery solution consisting of 99% *water* and is important as a *solvent* for soluble food nutrients. A lubricant, *mucin*, allows ease of swallowing of dry foods.

The main enzyme present in saliva is *amylase* which digests *cooked* starch-containing *dextrins*, producing *maltose* and also a small amount of fig 7.9 *the main regions of the human gut or alimentary canal*



glucose. Raw uncooked starch is changed by amylase into *dextrins*. Saliva pH is 6 to 7, almost neutral.

A round-shaped food *bolus* is formed by the action of tongue and the cheeks, and is swallowed, passing down the *oesophagus* by peristalsis.

Experiment 7.1 *to investigate the action of saliva*

Procedure

(i) Rinse all traces of food and particularly sugars from the mouth. Collect a sample of saliva and find its pH value using a universal indicator test paper.

(ii) Prepare a 2% suspension of raw uncooked starch powder in water.
(iii) Prepare a suspension of powdered *non-sweetened* water biscuit or oatcake in water.
(iv) Add a saliva sample to each test tube and maintain the contents at 40°C in a water bath for 10 min.
(v) Test small samples from each test tube with: (a) iodine solution; (b) Benedict's solution, and (c) Clinistix reagent strips.

Observations

Iodine solution does not turn blue-black, showing the starches have been *changed*. Benedict's solution shows the presence of *reducing* sugars, either maltose or glucose, in the biscuit suspension. *Glucose* is shown to be present in the biscuit suspension by means of the Clinistix reagent strip.

(b) Digestion in the stomach

Gastric juice is secreted from the *gastric gland* cells lining the stomach, at the daily rate of 2 to 4 litres. The food is blended and churned with the gastric juice by *peristalsis* of the stomach wall, to produce a creamy *chyme*.

Gastric juice is strongly *acid*, with a pH between 1 and 2. It consists of 98% water, 0.5% hydrochloric acid, the lubricant *mucin*, and the enzymes *pepsin* and *lipase*. In young children the enzyme *rennin* is also present.

Hydrochloric acid provides the necessary pH for enzyme action. It also stops the action of swallowed saliva. Nucleoproteins are split into protein and nucleic acids. Food is also *disinfected* by the bactericidal action of hydrochloric acid.

Pepsin commences the breakdown of proteins in simpler proteins called *polypeptides*.

Lipase, found only in young children, acts upon *small* amounts of lipids to produce fatty (alkanoic) acids and glycerine (propanetriol).

Rennin is active in the stomachs of babies, changing soluble *caseinogen* of milk into *insoluble* curds of protein *casein*. Commercial preparations of *rennin extract* from calves stomachs are used in making milk *junkets*.

Experiment 7.2 ***to show the digestive action of pepsin***

Procedure

(i) Suck up egg white into narrow glass capillary tubes and cook them in boiling water to denature and coagulate the protein.
(ii) Prepare a 2% solution of pepsin and divide between three test tubes and add cooked egg white in capillary tubes to each.
(iii) Using universal indicator test paper, adjust the pH of one test tube to pH 1 or 2 by adding a little dilute hydrochloric acid, dropwise. Use

dilute sodium hydroxide solution to adjust the pH of another solution to pH 12-13. Leave the remaining solution neutral at pH 7.
(iv) Maintain the test tubes in a water bath at 40°C for up to 30 min.

Observations

The cooked egg white is seen to disappear in the *acid* enzyme solution, but remains undigested in the neutral and alkaline solution. It is therefore evident that pepsin enzyme will only function in an *acid* pH 1 or 2 solution. Different enzymes require different pH values for optimum activity.

(c) Digestion in the small intestine

Periodically *chyme* is allowed to leave the stomach by way of the *pyloric sphincter* muscle which guards the entry into the small intestine. The small intestine is 6 m in length and occupies 65% of the total gut length.

Duodenum is the first 30 cm of the small intestine, and it receives *three* main secretions, one each from the liver as *bile juice*, the pancreas as *pancreatic juice* and the duodenum wall as *intestinal juice*.

(i) *Bile juice*

This is produced at the rate of about 700 cm^3 to 1.2 litres daily. It is a yellowish green liquid with an alkaline pH of about 8. It consists of 98% water and contains *bile salts* which are emulsifying agents able to change lipids physically into *emulsions*. The emulsions consist of tiny lipid oil droplets with a great *surface area.*

Excretory products such as bile pigments and cholesterol produced by the liver are also present in bile juice. Bile juice does *not* contain any digestive enzyme.

The liver has *many* functions apart from bile juice formation and these are described in Section 12.2 under homeostasis.

(ii) *Pancreatic juice*

This is produced by the pancreas at the rate of about 700 cm^3 daily; it has an almost *neutral* pH value of 7 to 8. It contains the following enzymes:

(1) *amylase*, to complete the conversion of starch into maltose;
(2) *lipase*, which converts *most* of the lipid in a meal into fatty (alkanoic) acids and glycerine (propanetriol);
(3) *nuclease*, digesting RNA and DNA nucleic acids; and
(4) *trypsinogen*, an inactive forerunner of *trypsin*. Trypsinogen is converted into trypsin by *enterokinase*. Trypsin is a powerful protein enzyme, changing proteins into *polypeptides.*

(iii) *Intestinal juice*

This is produced by glands in the wall of the small intestine and duodenum at a rate of 200 cm^3 daily. In the duodenum it has an acid pH of 4.5 to 6, whilst elsewhere in the small intestine it has a pH of 6 to 7. It contains the following enzymes which *complete* the process of food digestion in man:

1. *enterokinase*, to convert trypsinogen to trypsin;
2. *glycosidases* (maltase, sucrase, lactase), which convert maltose, sucrose and lactose into the *monosaccharides* (glucose, fructose and galactose);
3. *lipase*, to complete digestion of any lipid not digested by pancreatic juice;
4. *erepsin*, which changes all polypeptides into *amino* acids; and
5. *nuclease*, which converts nucleotides into phosphate, ribose sugar and different nitrogen bases, adenine, etc.

Experiment 7.3 *to show the digestive action of trypsin*

Procedure

(i) Prepare a 2% solution of trypsin in water.
(ii) Cut up strips of photographic film negatives.
(iii) Place negative strips in a trypsin solution, and in a 'control' of plain water.
(iv) Maintain the solutions at 40°C in a water bath and carefully observe the negative strips.

Observations

Film negatives are plastic cellulose acetate coated with *gelatine* impregnated with black *silver*. Trypsin digests the gelatine, changing it into soluble *polypeptides*. The black silver metal is seen to fall away, leaving a clear plastic film base.

Table 7.3 summarises the processes of digestion in man.

7.8 ABSORPTION

Absorption occurs in the stomach, small intestine and large intestine.

(a) Stomach
Water, glucose, ethanol, certain minerals, vitamins and certain drugs may be absorbed by osmosis, diffusion and active transport into cells lining the stomach.

(b) Small intestine
This is the main region of absorption of products of digestion,

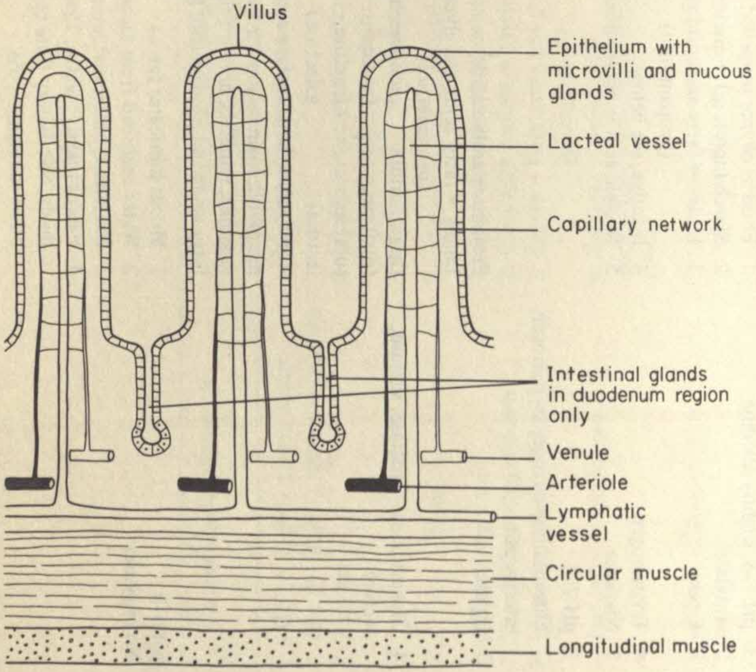
Table 7.3 *summary of digestion in man*

Region of gut	*Gland and secretion*	*Enzymes and optimum pH*	*Food digested, products and other activity*
Mouth Mastication by jaws and tongue	Salivary gland – saliva, 1-2 litres daily	1 pH 5-7, slightly acid in adults, slightly alkali to neutral in children 2 Amylase	1 Mucin lubricates food bolus 2 (a) Starch (amylose) → dextrins (b) Cooked starch → maltose (+ trace glucose)
Oesophagus	None	None	Food bolus moves by peristalsis
Stomach Churning action. Temporary storage, 1 to 3 h	Gastric gland, stomach wall – gastric juice, 2–4 litres daily	1 pH 1, strongly acid 2 Rennin (in young children) 3 Lipase (in young children) 4 Pepsin from pepsinogen	1 Hydrochloric acid is *bactericidal* 2 Clots milk protein → casein 3 Lipids → fatty acids and glycerine (propanetriol) 4 Proteins → amino acids *Absorption*: water, salts, vitamins and ethanol
Duodenum	1 Liver – bile juice, 700 cm^3 - 1.2 litres daily	1 pH 7-8, slightly alkaline 2 No enzyme	1 Alters pH of stomach contents 2 Bile salts emulsify or cream lipids

	2 Pancreas – pancreatic juice, 700 cm^3 daily	1 pH 7–8, slightly alkaline	1 Food as *chyme* propelled by peristalsis
		2 Amylase	2 Starch (amylose) → maltose
		3 Lipase	3 Lipids → fatty acids and glycerine (propanetriol)
		4 Trypsinogen	4 Inactive, see below
		5 Nuclease	5 Nucleic acid → nucleotides
Small intestine and duodenum	Glands in intestine and duodenum wall – intestinal juice, 200 cm^3 daily	1 pH 7–8	
		2 Enterokinase changes trypsinogen into trypsin	
		3 Lipase	Proteins → amino acids Lipids → fatty acids and glycerine (propanetriol)
		4 Glycosidases – maltase, sucrase, lactase	Disaccharides (maltose, sucrose, lactose) → monosaccharides (glucose, fructose, galactose) *Absorption*: large surface area, villi and microvilli, main region for absorption of vitamins, minerals, amino acids, glucose, fatty acids and propanetriol (glycerine)
Large intestine	Lining with mucous glands	pH 6–8 No enzymes	1 Mucus lubricates faeces 2 Water absorbed from faeces 3 Bacteria synthesise vitamin B groups 4 Faeces mainly: water, 75%; bacteria, 8%; lipids, 6%; dietary fibre cellulose, 2%; other substances, 9%

monosaccharides, amino acids, fatty (alkanoic) acids and glycerine (propanetriol). The internal *surface area* is greatly increased by *infoldings* and by finger-like projections called *villi* (Fig. 7.10).

fig 7.10 *structure of the small intestine wall*



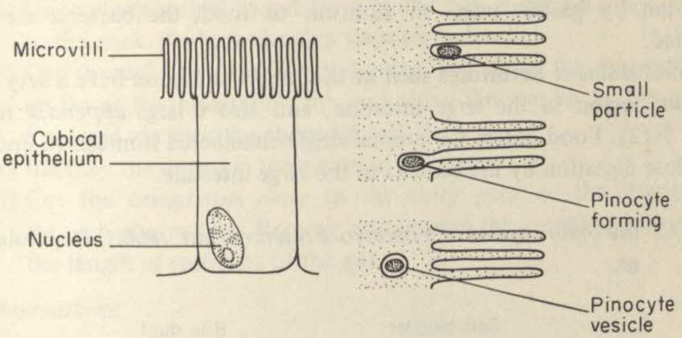
Each *villus* is constantly contracting and relaxing and in doing so aids transport of nutrients which enter the capillary vessels and lacteal vessel. Uptake is by diffusion and active transport, the fatty (alkanoic) acids and glycerine (propanetriol) entering the lacteal vessel, whilst all other soluble nutrients enter the capillary vessels.

The outer surface of the *epithelium* lining the small intestine (Fig. 7.11) has numerous *microvilli*; these are able to engulf small food particles and fluid by a process called *pinocytosis*.

(c) Large intestine

Water absorption occurs in the *colon* region, together with the active uptake of certain mineral ions. Most of the water present in the original saliva, gastric, bile and pancreatic juices is recovered by absorption.

fig 7.11 *small intestine epithelium showing microvilli and pinocytosis*



Mucus, containing mucin, is secreted to lubricate the *faeces*; these consist mainly of indigestible *dietary fibre*, bacteria and dead *epithelial* cells removed from the gut lining by mechanical wear of food material.

The only nutrients which do not require digestion in man are *water*, *mineral* salts and ions, ethanol and the *vitamins*.

(d) Egestion

Faeces remain in the large intestine until a short time before the act of egestion or *defaecation*, when they move into the *rectum* which is normally empty.

The presence of faeces in the rectum causes *involuntary* contraction of the rectum wall, and relaxation of the anus *sphincter* muscle. Voluntary contractions occur in the diaphragm and abdomen muscles which help to eject the faeces.

7.9 THE HERBIVORE MAMMAL GUT

Food of herbivore mammals, rabbit, horse or cow, consists mainly of the carbohydrate *cellulose*, chemically composed of *glucose* units. Cellulose can be changed into glucose by the enzyme *cellulase*, but herbivore mammals are unable to secrete this enzyme.

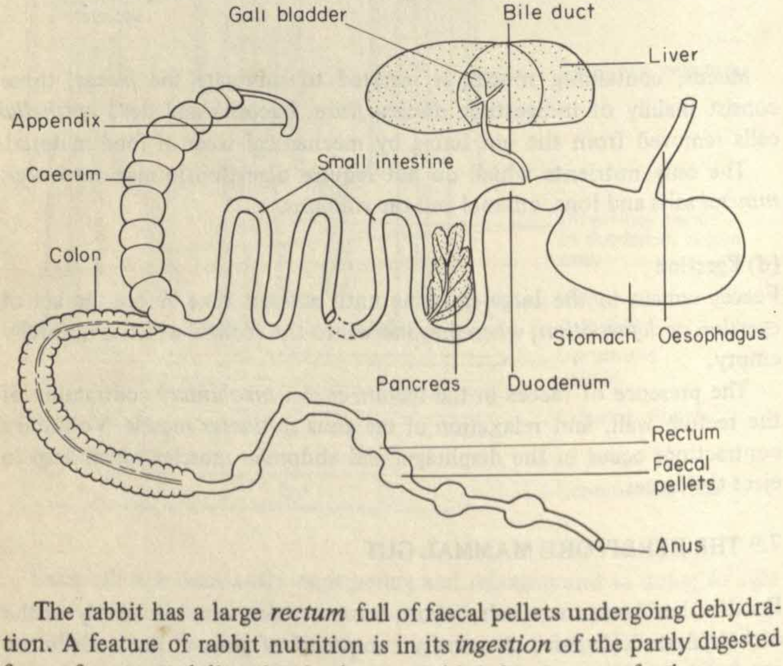
Digestion occurs by means of bacteria which inhabit the gut. These bacteria secrete the enzyme cellulase.

Prolonged chewing, using the ridged herbivore teeth, breaks down the cellulose walls, releasing their protein, starch, nucleoprotein, vitamin and mineral cell contents.

Ruminant sheep, goats and cows have a *four*-chambered stomach. Food enters the *rumen* and *reticulum* chambers to undergo digestion of cellulose by the *bacteria*. Periodically, portions of food are regurgitated into the mouth as 'cud', and rechewed and reswallowed to enter the *psalterium* chamber, and then pass into the 'normal' stomach or *abomasum* for digestion by gastric juice. In addition to food, the bacteria are also digested.

Non-ruminant herbivores such as the rabbit and horse have a very large *caecum* region in the large intestine, and also a large *appendix* region (Fig. 7.12). Food enters the normal single-chambered stomach to undergo cellulose digestion by the bacteria in the large intestine.

fig 7.12 *the main regions of a herbivore mammal gut, rabbit,* Oryctolagus *sp.*



The rabbit has a large *rectum* full of faecal pellets undergoing dehydration. A feature of rabbit nutrition is in its *ingestion* of the partly digested faeces for repeated digestion in the gut – this is known as *refection.*

In comparison the herbivore mammal gut is much longer in length, and food takes a longer time to pass through it compared to the shorter gut of a carnivore mammal.

Experiment 7.4 *dissection of the gut of a mammal*

Procedure

(i) Examine the teeth in the mouth of a dead rabbit. Note also the position of the anus.

(ii) Place the rabbit on its back on a board and fix it down with dissecting points passed through the limbs.

(iii) Use a sharp scalpel to cut through the skin along the mid-ventral line to the neck. Pin back the skin flaps on each side.

(iv) Cut through the muscular abdominal wall along the mid-ventral line as far as the breastbone tip, and along the margin of the rib cage. Fold and pin back the abdomen wall flaps.

(v) Identify the organs in their natural positions.

(vi) Cut the oesophagus close to the entry point to the stomach, and through the rectum. Remove and unravel the complete gut. *Measure* the length of each part of the gut.

Observations

During dissection, cut upwards and outwards, rather than downwards and inwardly, as this may lead to cutting of tissues and organs hidden beneath.

Dispose of material by wrapping in old newspaper and burning or by deep burial in garden soil.

Thoroughly wash and scrub your hands after every dissection.

7.10 QUESTIONS

1 Draw a labelled diagram showing the structure of a mammal tooth. Name the different types of teeth in an adult man and state their functions. Describe the functions of the tongue, saliva and oesophagus. How is it possible to drink fluids standing upside down?

2 Draw a labelled diagram of the alimentary canal of man. Give an account of where and how carbohydrates are digested. Describe the feeding methods in a protozoan and a coelenterate animal.

3 Give a brief account of the chemical nature and function of enzymes. Describe a *controlled* experiment showing the action of pepsin on egg white.

4 Describe how and where water is absorbed in the alimentary canal. How does this absorbed water reach the bile juice and what is the function of bile juice in digestion?

5 Explain the following terms with examples: (a) ingestion; (b) egestion; (c) digestion; (d) emulsification; (e) assimilation; (f) absorption.

6 The following data show the time it takes to empty the stomach of 100 g portions of different foods. Construct a histogram to compare the stomach emptying times. Explain why some foods take longer to leave the stomach than others.

Emptying time (h. min)	2.00	3.15	2.00	1.00	3.30	3.00
Food	jelly	pork	sweets	milk	nuts	cakes

CHAPTER 8

FOOD AND MAN

8.1 FOOD FUNCTIONS

Digested food is absorbed into the blood and transported as the following *soluble nutrients*: glucose and other monosaccharides, amino acids, fatty (alkanoic) acids, glycerine (propanetriol), vitamins, mineral ions, water and possibly ethanol.

Nutrients are used by body cells for the following functions:
(i) *growth* and *repair* of body tissues, muscle, bone, teeth and skin;
(ii) *energy* for cell metabolism, heat, work and glandular activity;
(iii) *protection* from disease and infection;
(iv) *maintenance* of chemical composition of cells.

8.2 FOOD COMPOSITION

Foods are generally complex *mixtures* of different chemical compounds or nutrients. Some foods are composed of *one* nutrient: for example, refined cane sugar is 100% *sucrose*, refined lard is 99% lipids.

Chemical analysis is used to determine the chemical composition of foods and results are recorded in various food composition tables.

Table 8.1 shows the composition of *edible* portions of different foods, the portion remaining after removing shells, skins and bones. The quantity of each nutrient present in 100 g is indicated in grammes (g), milligrammes (mg) and microgrammes (μg). These values can easily be converted into *percentage* composition by weight. For example, the percentage of main nutrients in cheddar cheese is: water 37%, protein 25%, lipids 35% and carbohydrate 2%. *Pie* diagrams can be drawn for any food using the food composition tables.

The human body has the following chemical composition: water 70%, lipids 15%, protein 12%, carbohydrate 0.5%, minerals and vitamins 2.5%. A purpose of food is to *maintain* the *chemical composition* of the human body within the limits indicated by its chemical analysis.

Table 8.1 *composition of 100 g edible portion of some foods. (Reproduced by permission of CIBA-Geigy from Documenta Geigy Scientific Tables)*

									Vitamins					
Food	*Water* (g)	*Protein* (g)	*Lipid* (g)	*Carbo-hydrate* (g)	*Fibre* (g)	*Energy value* (kJ)	*Calcium* (mg)	*Iron* (mg)	*A* (μg)	B_1 (mg)	B_2 (mg)	*Nicotinic acid* (mg)	*C* (mg)	*D* (μg)
Apple, sweet	84	0.3	0.4	15	0.9	244	6	0.3	–	0.04	0.02	0.2	30	–
Orange	87	0.9	0.2	11	0.8	190	33	0.4	8.0	0.08	0.03	0.2	49	–
Cabbage	92	1.6	0.1	6	1.0	105	43	0.6	50.0	0.06	0.05	0.2	60	–
Peas (canned)	82	3.4	0.4	13	1.3	290	25	1.8	50.0	0.11	0.06	0.9	10	–
Potato chips	3	6.7	37.0	49	1.1	2285	25	1.8	–	0.18	0.11	3.2	10	–
Peanuts (roasted)	5	30.0	46.0	18	3.3	2350	74	1.9	–	0.30	0.15	21.0	–	–
Bread, wholewheat	37	9.3	2.6	49	1.5	1010	96	2.2	–	0.30	0.13	3.0	–	–
Cornflakes	4	7.9	0.7	80	0.6	1500	10	1.0	–	0.16	0.08	1.6	–	–
Rice (cooked)	74	2.2	0.1	23	0.1	420	8	0.2	–	0.01	0.01	0.4	–	–
Chocolate, milk	1	6.0	33.5	54	0.5	2275	216	4.0	6.6	0.10	0.04	0.8	–	–
Jam	28	0.5	0.3	71	0.6	1165	12	0.3	2.0	0.02	0.02	0.2	6	–
Butter	15	0.6	81.0	0.4	–	3007	16	0.2	995.0	–	–	0.1	–	1.26
Cheddar cheese	37	25.0	32.0	2.0	–	1670	680	0.9	420.0	–	0.83	1.6	–	0.35
Milk (pasteurised)	87	3.3	4.0	4.9	–	270	125	0.1	44.0	0.04	0.15	0.9	1.8	0.05
Egg, whole (raw)	74	12.8	11.5	0.7	–	660	54	2.7	140.0	0.12	0.34	0.1	–	3.4
Bacon, medium fat	13	25.0	55.0	1.0	–	2550	25	3.3	–	0.48	0.31	4.8	–	–
Liver, beef (raw)	70	20.0	4.0	3.6	–	570	8	12.6	6000	0.27	2.80	16.0	31	0.75
Herring (raw)	73	19.0	8.0	–	–	570	20	1.1	45	0.01	0.33	4.0	–	20–100
Cod (raw)	82	16.5	0.4	–	–	295	18	0.9	–	0.10	0.07	2.17	2	–

8.3 ENERGY VALUE OF FOOD

The *heat* energy produced by the complete combustion or burning of a known *weight* (mass) of food can be measured by recording the increase in *temperature* of a known weight (mass) of *water* using an apparatus called the *calorimeter* (Plate 8.1). The temperature of 1 g of water will be raised 1°C by 4.2 J of heat energy.

plate 8.1 *the food calorimeter, an apparatus used to find the energy value of a food sample (Griffin and George Ltd)*

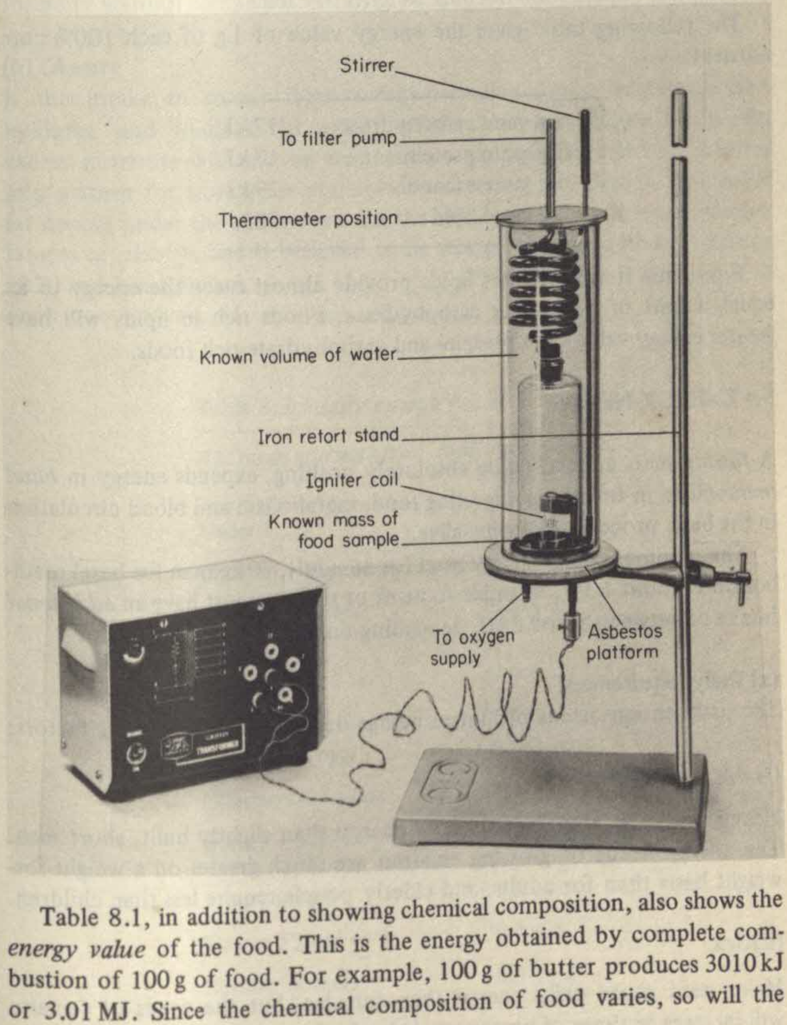


Table 8.1, in addition to showing chemical composition, also shows the *energy value* of the food. This is the energy obtained by complete combustion of 100 g of food. For example, 100 g of butter produces 3010 kJ or 3.01 MJ. Since the chemical composition of food varies, so will the

energy values, some food having a higher energy value than other food. The energy value of butter (3010 kJ) is over 12 times the energy value of an equal weight of apple (244 kJ).

(a) Energy value of nutrients

Water, vitamins, mineral ions and roughage have NO energy value. (Cellulose fibre in herbivore animals *has* an energy value since cellulose is digested into glucose.)

Pure, 100% samples of the different energy-giving nutrients, carbohydrates, lipids, proteins and ethanol provide *different* amounts of energy on complete combustion of *equal* weights of each.

The following table gives the energy value of 1 g of each 100% pure nutrient:

1 g pure carbohydrate	17 kJ
1 g pure protein	17 kJ
1 g pure ethanol	29 kJ
1 g pure lipid	38 kJ

From this it is seen that lipids provide almost *twice* the energy of an equal weight of protein or carbohydrate. Foods rich in lipids will have *greater* energy value than protein- and carbohydrate-rich foods.

8.4 ENERGY NEEDS

A *fasting* man at rest, doing absolutely nothing, expends energy in *basal metabolism* in breathing, digesting food, metabolism and blood circulation in the basic process of keeping alive.

The minimum daily energy need for an adult, 70 kg man for basal metabolism is about 6 MJ. In order to *work* or *play* he must have an *additional* intake of between 5 and 8 MJ, depending on the activity engaged in.

(a) Daily requirement

The daily energy needs of human beings depend on the following factors:

(i) *Age and body size*

Heavy-built, tall men require more energy than slightly built, short men. The energy needs of growing children are much greater on a weight-for-weight basis than for adults, and elderly people require less than children.

(ii) *Sex*

Males need more daily energy than females, but the needs of females will increase in times of pregnancy, baby feeding and menstruation.

(iii) *Work*

Physical activity in work and recreation varies with the job or the sport. *Sedentary* work, for example driving buses, is less energy-demanding than digging trenches or hewing coal.

Sitting, standing, walking or running involve different energy expenditure in muscles. Football and swimming are energy-consuming sports.

(iv) *Climate*

Cold climates result in a greater intake of high-energy foods to provide for body warmth compared to that needed in hot climates.

(b) Obesity

If the intake of energy from energy-providing foods, proteins, carbohydrates and lipids is in *excess* of the human body's *needs* , the excess nutrients will *not* be excreted or egested but will be converted into a form for *storage*, as *glycogen* in liver and muscles, or lipid *fat* in fat depots under the skin or around the kidneys. This leads to overweight, fatness or *obesity*, and is believed to be related to sugar diabetes (Section 12.3) and heart disease.

Table 8.2 *daily energy needs*

Age range and activity	*Daily energy needs* (MJ)
Under 1	3.3
Children 1-8 years	5.0-8.8
Males 9-17 years	10.5-12.6
Men 18-64	
sedentary	11.0
very active	15.0
Men 65 and over	9.0-10.0
Females 9-17 years	9.6
Women 18-54	
most activities	9.2
very active	10.5
Women 55 and over	8.0-8.6
Nursing mothers	10.0-11.5

(c) Slimming

Weight loss is achieved by modifying the food *intake*, and in consuming the body's own lipid food reserve. Diets for reducing body weight have an energy value of 4 MJ daily, and are low in *carbohydrate* content.

Table 8.2 summarises the daily energy needs of human beings.

8.5 CARBOHYDRATES IN FOODS

(a) Sources

The main carbohydrates in food are *starches*, *sucrose* and *glucose* present in foods of plant origin, and also include *cellulose* which cannot be digested in man. *Glycogen* and blood sugar glucose are components of foods of animal origin.

Table 8.1 shows the carbohydrate component of different foods.

In the United Kingdom, carbohydrates may form between 50 and 70% of the daily diet, whilst in Eastern countries it may be over 90%. The United Kingdom carbohydrate intake is 50% starches in cereals and vegetables, 40% sucrose in sweets and jams, and 10% milk and fruit sugars.

(b) Functions

Carbohydrates provide *energy*, and they *spare* the use of protein in a meal.

(c) Health aspects

The high daily intake of sucrose is believed to be linked with increased tooth decay, heart disease and obesity. A rise in blood sugar above its normal limit causes sugar diabetes.

Experiment 8.1 *to test foods for starch and glucose*

Procedure

Use iodine solution and Clinistix reagent strips to test for starch and glucose in the foods listed in Table 8.1, using the procedure in Experiment 4.5.

8.6 LIPIDS IN FOODS

(a) Sources

Lipids in the diet are either of *animal* origin (butter, lard, cheese, meat and fish) or *plant* origin (margarine, cooking oils, nuts and seeds).

Lipids, mainly from plant sources, contain *essential fatty acids* which cannot be made in the human body, and which play an important part in certain metabolic processes. Sunflower, soyabean and peanut oils, components of cooking oils, are rich in essential fatty acids.

Table 8.1 summarises the lipid composition of different foods.

(b) Functions

Between 20 and 40% of the daily United Kingdom diet consists of lipids, obtained mainly from butter, margarine, meat, fish, milk and cheese.

Lipids are an important component of the human body, being present to the extent of 10 to 15% of body weight and forming part of the *lipoprotein* cell membrane or plasmalemma.

(i) Lipids are a concentrated *energy* reserve.
(ii) *Essential fatty acids* are needed to stimulate growth, maintain skin and reproductive efficiency.
(iii) *Insulation* of body heat is by the skin fat depot.
(iv) *Protection* is provided in surrounding certain organs, e.g. kidneys.
(v) *Vitamins* A, D, E and K are associated with most natural lipid-containing foods.
(vi) *Flavour and texture* of foods is improved by adding or cooking in lipids.

(c) Health aspects

Animal origin lipids, eggs and meat, contain *cholesterol*; this is not present in plant origin lipids. Cholesterol is also formed in the human liver, and the substance circulates in the blood. Blockage of the *coronary artery* is believed to be caused by cholesterol deposits, and gallstones of the liver are composed of cholesterol.

8.7 PROTEINS IN FOODS

(a) Sources

About 10% of the United Kingdom daily diet is protein. It is much higher in meat-eating South American countries, and very low in certain Eastern countries.

Animal origin protein, meat, fish, eggs, milk and cheese, provide 60% of the daily protein intake. *Plant* origin protein, bread, cereals, potatoes, peas and beans, make up the remaining 40%.

(i) *Essential amino acids*

Twenty different amino acids enter into the composition of all known proteins. Proteins *differ* in different living organisms, *plant protein* differs from *animal protein* and the proteins in human beings differ from the proteins in cows' tissues.

Plants make *all* their own amino acids; mammals *can* make 10 to 12 kinds of amino acids. In order that a human being can make his own tissue *protein*, he must have another *eight* different *essential amino acids* in its cells and these must come from its protein food intake.

The eight *essential amino acids* are: isoleucine, leucine, methionine, phenylalanine, threonine, lysine, tryptophan and valine. Growing children need an extra *two*, arginine and histidine.

Animal origin protein can supply *all* eight or ten essential amino acids, but most protein from plant sources is deficient in one or more of these essential amino acids.

Animal origin protein containing the full range of essential amino acids is called *high biological value* (HBV) protein, whilst plant origin protein deficient in some essential amino acids is called *low biological value* (LBV) protein.

Human milk and eggs provide a source of HBV, whilst *gelatine*, a protein from skin and bones, is a LBV protein.

Table 8.1 summarises the protein content of different foods.

(b) Functions

Proteins form 12 to 18% of the human body composition mainly in muscles, bones and skin, and in the *lipoprotein* of cell membranes or the plasmalemma, and *nucleoprotein* of cell nuclei.

(i) *Structural proteins* are needed to build and repair new and damaged muscle, bone and skin tissues.

(ii) *Functional proteins*, enzymes, hormones and blood components are essential for cell metabolism.

(iii) *Energy* can be provided by respiration of protein amino acids. This occurs in *starvation* of human beings. Amino acids are *deaminated* in the liver and changed into carbohydrate.

(c) Health aspects

Phenylketonuria is an inherited condition with the inability to metabolise *phenylalanine* which is one of the essential amino acids.

Coeliac disease is due to an inability to use *gluten* protein present in bread and most cereals. A gluten-free diet is needed to overcome the disease.

Kwashiorkor is due to a shortage of *protein* in the diet and is seen in weaned children aged 2 years (Plate 8.2), who were previously breast-fed and obtained protein from human milk. Weaning onto mainly a *starchy* diet without protein causes the symptoms of distended stomach, muscle wasting and anaemia.

Marasmus is due to shortage of *all* nutrients or starvation seen as wasting and emaciation of young infants (see Plate 20.4).

(d) Protein daily needs

A person in good health requires *one* gramme of high biological value

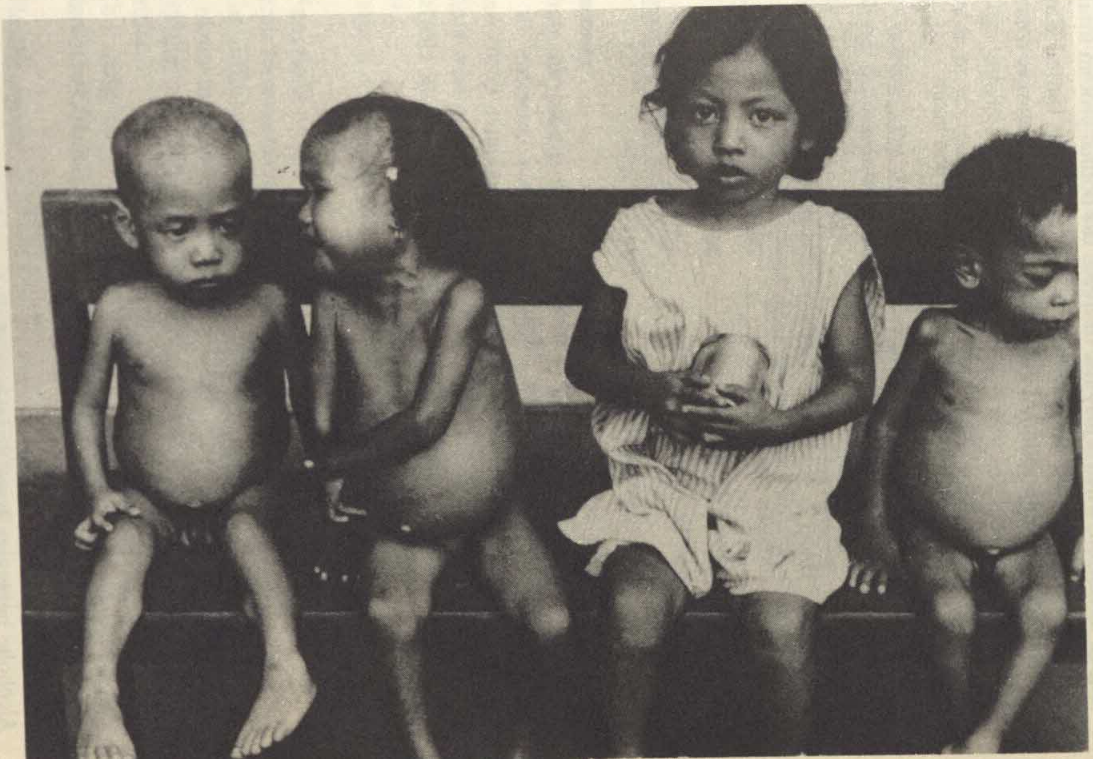


plate 8.2 *four children of the same age, three of whom suffer from protein deficiency — kwashiorkor (World Health Organisation)*

protein to every kilogramme (1000 g) of body weight daily. A 70 kg adult requires 70 g of HBV protein daily.

Protein intake is *increased* in expectant and nursing mothers, and a higher intake is needed for tissue repair in bone fractures, or after a surgical operation, when it may rise to *treble* the normal protein intake.

Table 8.3 shows the main sources of protein in the United Kingdom diet and protein composition of different foods.

Table 8.3 *daily protein requirements and main sources in the diet*

Age range	*Daily protein needed* (g)
Under 1	15-20
Children 1-8 years	20-50
Males 9-17 years	36-75
Men 18-65 years	45-90
Men 65 and over	38-59
Females 9-17 years	35-58
Females 18-55 years	38-63
Females 55 and over	36-51
Nursing mothers	45-68

Sources in United Kingdom diet

Cereals, bread and flour	35%
Dairy products	28%
Meat, fish and poultry	25%
Potatoes and other foods	12%

8.8 ETHANOL

Ethanol is a product of *anaerobic* respiration (see Section 10.3).

(a) Sources

Alcoholic beverages have a varying ethanol content; beer and ales 4-6%, wines 15%, fortified wines, sherry and port 15-20%, spirits, gin and whisky 30-40%. Certain wines and liqueurs are sweetened with added sucrose or honey.

(b) Functions

Ethanol does not require digestion, and is absorbed directly in the stomach or small intestine.

(i) Ethanol can provide *energy* (Section 8.3).
(ii) *Digestive juices* are stimulated by alcoholic aperitifs.

(c) Health aspects

Although ethanol may *act* as a nutrient in providing energy, the dangers to health in excessive consumption place it in a class apart from normal nutrients.

Alcoholism gives rise to intoxication with increasing concentration in the blood fluids. Levels of 0.4 to 0.5% ethanol in blood cause coma and death.

Alcoholics suffer protein, mineral and vitamin deficiency, with nervous and muscle disorders, and final death from liver failure or *alcoholic cirrhosis*.

8.9 MINERALS IN FOODS

(a) Sources

Minerals are present in foods as *salts* or *inorganic* compounds, usually as *ions* of calcium, sodium, carbonate, sulphate, chloride and fluoride. *Organic* food components may contain different chemical elements, for example *iron* in blood haemoglobin. Drinking water may contain a range of soluble inorganic salts, more being present in hard water than in soft water.

Table 8.4 shows the mineral components of different foods.

(b) Functions

Minerals have *no* energy value.

The different functions of the minerals are summarised in Table 8.4. The *major* minerals enter into the *construction* of different body tissues, whilst the *trace* minerals are mainly concerned with different *metabolic* activities.

The daily needs of the major and trace elements are measured in *milligrammes* (mg).

(c) Health aspects

Various disorders arise through *deficiency* of different minerals.

Anaemia is due to *iron* deficiency, arising from insufficient iron in diet, bleeding or inability to absorb iron in the gut. Symptoms are tiredness, pale skin and breathlessness.

Table 8.4 *minerals: sources, daily needs, body content and functions*

Chemical element	*Sources*	*Estimated adult daily needs*	*Total weight and percentage in a 70 kg human body*	*Function*
Major minerals				
Calcium, Ca	Bread, flour, cheese, milk, vegetables, sardines	500 mg	1000 g (1.5%)	1 Bone and teeth formation 2 Blood clotting 3 Muscle activity
Phosphorus, P	Sardines, fish, eggs, meat, milk, cheese, potatoes, bread	1.4 g	700 g (1.0%)	1 Bone and teeth formation 2 Nucleic acid formation 3 Energy transfer, ATP
Sulphur, S	Eggs, meat, beans, peas, vegetables	850 mg	175 g (0.25%)	1 To form vitamin B_1 2 To form skin, nails and hair
Potassium, K	Beef, herring, eggs, milk, bacon, cheese, potatoes	3.3 g	140 g (0.2%)	1 Osmocontrol – blood and tissue fluid 2 Nerve impulse conduction
Sodium, Na	Salt, ham, bacon, cheese, bread, butter	4.4 g	105 g (0.15%)	1 Osmocontrol – blood and tissue fluid 2 Nerve impulse conduction 3 Gastric juice, HCl acid
Chlorine, Cl		4.4 g	105 g (0.15%)	

Magnesium, Mg	Cheese and green vegetables, and most foods	340 mg	35 g (0.05%)	1 Energy transfer, muscle 2 Bone and tooth formation
Trace minerals				
Iron, Fe	Bread, flour, meat, liver, eggs, green vegetables	10 mg	4 g	1 Blood haemoglobin formation 2 Muscle myoglobin formation 3 Enzyme activity
Copper, Cu	Liver, peas and beans	3.5 mg	0.1 g	1 Support the function of iron 2 Enzymes
Manganese, Mn	Tea, cereals	3.5 mg	0.02 g	1 Bone formation and growth 2 Protein formation
Iodine, I	Sea fish, salt	0.2 mg	0.03 g	Thyroid gland function
Fluorine, F	Sea fish, tea, and some drinking water	1.8 mg	2.6 g	Bone and teeth formation
Zinc, Zn	Meat, peas and beans	13.0 mg	2.3 g	1 Enzymes 2 Protein formation
Cobalt, Co	Meat and yeast	0.3 mg	0.001 g	Formation of vitamin B_{12}

Goitre is due to *iodine* deficiency, with a swollen thyroid gland and low metabolic rate.

Bone softening and brittleness are due to calcium deficiency, and vitamin A deficiency.

Muscle cramp in excessive sweating is caused by salt (sodium chloride) deficiency.

8.10 VITAMINS IN FOODS

Vitamins are organic chemical compounds with *different* chemical composition from each other. They are needed in *very small* daily amounts ranging from a few *microgrammes* (μg) to many *milligrammes* (mg) depending on the individual vitamin.

Most of the vitamins in the diet are obtained ready-made from plant and animal origin foods. A few can be made in either the skin by means of ultra-violet light, or in the gut by bacterial action.

Shortage of certain vitamins in the diet causes *deficiency diseases*, for example *scurvy* formerly seen in seafarers on long voyages without fresh food. This was corrected by either *fresh* food or eating lime fruits containing vitamin C (ascorbic acid).

Discovery of vitamins

The experimental research work conducted by the biochemist Gowland Hopkins (1861-1947) was related to the *chemical composition* of foods. Chemical analysis at that time indicated the then known nutrients to include carbohydrates, proteins, lipids and minerals. Vitamins escaped discovery since chemical techniques of analysis could not detect these different chemical compounds present in such *minute* quantities in foods.

Rats were fed with highly *purified* forms of the then known nutrients, milk, casein protein, starch, sucrose, lard and salts; all rats showed poor stunted growth. Other rats fed on the same diet, plus a small amount of *supplement* of fresh milk or yeast showed normal healthy growth and weight increase.

It was evident that the milk or yeast supplements, although containing the major nutrients, did so in such small quantities as to be insignificant compared to the pure nutrients. Milk and yeast provided *accessory food factors* apart from proteins, carbohydrates, lipids and minerals.

With improving chemical techniques the accessory food factors were extracted and their chemical composition determined, and later many of these now-called *vitamins*, were made artificially or *synthesised chemically*.

(a) Sources

Vitamins are grouped as: (a) lipid-soluble, vitamins A, D, E and K; and (b) water-soluble, vitamins C and the B group. Vitamins are named individually in addition to the alphabetical title.

Table 8.5 shows the sources and names of the main vitamins.

(b) Functions

Vitamins participate in various *metabolic* processes. The effects of vitamin deficiency together with the daily needs are summarised in Table 8.5. *Note* in particular the vitamin needs which are measured in microgrammes (μg) and those vitamins measured in milligrammes (mg).

(c) Health aspects

It is rare for vitamin deficiency disease to occur in the United Kingdom unless the diet is unbalanced and consists of only one or two kinds of food. This may arise in bottle- and breast-fed babies where the milk may be deficient in vitamin C (ascorbic acid) and vitamin D (cholecalciferol).

Developing countries with diets restricted to certain foods such as rice, maize or other single *staple* foods show an incidence of various deficiency diseases including *beri-beri*, *pellagra* and *rickets*.

An *excessive* intake of vitamin A (retinol) and vitamin D (cholecalciferol) can lead to ***vitamin poisoning*** with swelling of bone joints and skin disorders.

Experiment 8.2 *to show the presence of vitamin C (ascorbic acid) in food*

Procedure

(i) Dissolve one tablet of DCPIP (dichlorophenyl indophenol) in 50 cm^3 *distilled* water to form a blue-coloured solution.
(ii) Dissolve a 25 mg tablet of vitamin C (ascorbic acid) in 50 cm^3 distilled water.
(iii) Add the DCPIP solution by means of a dropper to the vitamin C solution and note *bleaching* of the blue colour.
(iv) Add DCPIP solution dropwise to small amounts of the following: fresh juice extracts: orange, cabbage, potato and tomato. Repeat the test on boiled and cooled juices.
(v) Test a fresh sample of urine.

Observations

The DCPIP test is a *specific test* for vitamin C (ascorbic acid). Different specific tests are used for other vitamins.

Boiling destroys 75% of the vitamin C content of fruits and vegetables.

Table 8.5 *vitamins: sources, daily needs, functions and deficiency*

Vitamin	*Sources*	*Estimated adult daily needs*	*Function*	*Deficiency effect*
Fat-soluble				
Vitamin A Retinol	Butter, margarine, fish liver oils, liver, milk, carrots, tomato, apricots	750 μg	1 Growth 2 Vision at night 3 Healthy moist membranes – nose, etc.	1 Night blindness 2 Low resistance to infection 3 Poor growth 4 Eye disorder – eye cornea becomes dry
Vitamin D Cholecalciferol	Butter, margarine, fish liver oils, eggs, oily fish, cheese, milk, *sunlight action on skin*	2.5 μg	1 Uptake of calcium and phosphorus 2 Teeth and bone formation	1 Rickets in children – bone bending, badly formed teeth 2 Softening of bones in adults
Vitamin E Tocopherols	Milk, wheatgerm, vegetable oils, egg yolk	Not known	1 Prevents lipid oil and fats going rancid 2 Preserves other vitamins	Causes sterility in rats
Water-soluble				
Vitamin B_1 Thiamine	Meat, milk, cereals, yeast, cheese, peas, potatoes	1.2 mg	*Coenzyme* in energy release	Beri-beri – loss of appetite, digestive disorder, body wasting, swelling of limbs

Vitamin B_2 Riboflavin	Meat, milk, yeast, cereals, cheese, peas, eggs	1.7 mg	*Coenzyme* in energy release	Skin and moist membrane soreness
Nicotinic acid	Meat, fish, cereal grains, yeast, potatoes	18 mg	*Coenzyme* in energy release	1 Digestive disorders 2 Nervous disorder – memory loss, depression 3 Blotch, scaly skin – pellagra
Vitamin B_{12} Cyanocobalamin	Meat, liver, yeast	30 μg	1 Growth 2 Development of red blood cells	1 Anaemia – blood deficient in red blood cells 2 Digestive disorders 3 Nervous disorders
Vitamin C Ascorbic acid	Blackcurrants, potatoes, sprouts, cabbage, tomatoes, oranges	30 mg	1 Binds cells together 2 Blood and blood vessel formation 3 Healthy moist membranes 4 Bone and teeth formation	1 Swollen, bleeding gums 2 Loose teeth 3 Anaemia 4 Joint pains 5 Body weakness – scurvy
Vitamin K Phylloquinone	Liver, eggs, green vegetables, rose-hips and strawberries	Made by bacteria in large intestine	For blood clotting	Bleeding from gums and beneath skin

Vitamin C in excess of the body requirements after storage of an amount is excreted unchanged in the urine.

8.11 FIBRE IN FOODS

Dietary fibre consists of the indigestible material of plant origin, *cellulose* of plant cell walls and *lignin* in thickened plant cell walls. Table 8.1 shows the fibre component of different foods.

(a) Sources

Cabbage, beans, peas, cereals and wheat bran have a high fibre content. Root vegetables such as *young* carrots have a low fibre content compared to older carrots which may be woody with *lignin*. Approximately 10 g is needed daily in the diet.

(b) Functions

(i) Dietary fibre is able to absorb water and therefore makes the faeces moist and bulky.
(ii) It *mechanically* stimulates the gut wall, encouraging contraction of gut wall muscles and *peristalsis* and the secretion of mucus.

(c) Health aspects

Without fibre, the faeces become hard and dry and compacted in the large intestine, causing *constipation*.

8.12 WATER

(a) Sources

Water forms 65 to 70% of the human body weight, and comes from three sources:

(i) *metabolic water*, the byproduct of respiration;
(ii) drinking water and beverages;
(iii) food component.

The water content of various foods is shown in Table 8.1. This water is *not* chemically combined and can be driven off by evaporation, as in the preparation of various dried or *dehydrated* foods, milk and potato powder.

(b) Functions

An adult is unable to survive more than a week without water, but can survive many weeks without food, provided he has water.

Water has several functions in the body, listed in Section 4.5.

(c) Health aspects

The main disorder arises through water *loss* or inadequate *intake*, leading to *dehydration* (Sections 12.5 and 12.7).

Experiment 8.3 *to estimate water in foods*

Procedure

(i) Water is tested for *qualitatively* by means of anhydrous copper sulphate, which turns from white to blue in colour in the presence of water. Mix small quantities of food samples with copper sulphate using a flat-bladed knife, and watch for colour changes.

(ii) Weigh an evaporating dish empty and weigh into it about 100g of minced carrot or cabbage. Heat the dish over water boiling in a large beaker. Continue heating at 100°C until the sample reaches constant weight.

(iii) Weigh the dish and its dried contents and determine the loss in weight. Calculate the percentage water content as follows:

$$\text{percentage water in food} = \frac{\text{loss in weight}}{\text{original weight}} \times 100$$

8.13 A BALANCED DIET

A *balanced diet* will contain certain essential component nutrients in varying and adequate amounts from different food sources.

Government Health Departments recommend certain daily diet requirements for *energy* or of particular *nutrients*.

The present daily United Kingdom intake of nutrients is made up as follows: carbohydrates 50–70%, lipids 20–40%, and about 10% proteins.

8.14 QUESTIONS

1 What are food nutrients? Give the name of each type of nutrient and explain their function. Which substances eaten by man have little or no nutrient value?

2 What raw materials are needed by green plants to make amino acids? Which foods provide man with all the *essential* amino acids and which are defective in essential amino acids? What is the purpose of amino acids in the human body?

3 Which foods provide the human body with energy? Give examples of two foods with a *high* energy value and two with a *low* energy value. What are the daily energy requirements of an active man approximately?

4 What is meant by a balanced *meal* and a balanced *diet*? What diseases are caused by an inadequate diet? Which food nutrients are protective?

5 Draw pie diagrams using the information given in the food composition tables (Table 8.1) for the following food items, indicating their water, protein, carbohydrate and lipid content: (a) apple; (b) fried potatoes; (c) roasted peanuts; (d) milk chocolate; (e) fresh milk; (f) fried bacon.

6 The following data indicate the recommended daily protein needs of *males* in childhood and adulthood. Draw a graph and explain why the protein intakes vary with age.

Age	1-2	3-4	6-7	9-10	11-12	14-15	17-19	25	45	65
Daily protein intake (g)	40	50	63	72	82	100	110	70	70	70

CHAPTER 9

TRANSPORT

9.1 INTRODUCTION

Living organisms have the need to move substances into and out of cells and between neighbouring cells by a *transport system.*

Substances are transported in living organisms as:

(i) *solutions* of *soluble* nutrients, excretory waste, enzymes, hormones or constructional materials, dissolved in *water*;

(ii) *solids* in the form of food particles, blood cells, faeces, chloroplasts and cell organelles;

(iii) *gases* such as oxygen, carbon dioxide and water vapour in leaves and lungs.

Transport systems are of two main kinds. *Short-distance* transport systems are used in all living organisms and involve transport of *small* amounts of substances over very short distances within or between *cells.*

Long-distance transport systems are found in higher multicellular organisms. Long-distance transport involves the movement of *large* amounts of substances through tubular vessels or *vascular* systems, between tissues in widely spaced body regions.

Plants transport solutions in the vascular system of vascular *bundles*, whilst animals transport substances in the *blood* vascular system.

Peristalsis is the movement of substances caused by involuntary muscular contraction of the surrounding body wall in the *alimentary canal, ureters* and the *uterus*. This provides means of moving food through the gut, urine to the bladder and the birth of a mammal.

9.2 PRINCIPLES OF TRANSPORT; TRANSPORT IN SIMPLE ORGANISMS

The *physical processes* of diffusion, osmosis and active transport provide the means for transport to take place. These processes are compared in Table 9.1.

Table 9.1 *comparison of diffusion, osmosis and active transport*

	Diffusion	*Osmosis*	*Active transport*
1	*Liquids* and *gases* can diffuse over considerable distances	*Water* only transported over a short distance	Certain *selected* solutes, ions, glucose, sucrose, amino acid, etc., transported through short distance
2	*Rapid* in *gases*, but *slow* in solutions of substances	*Slow* process	*Rapid* process
3	Transport from *high* to *low* concentration along a *gradient*	Transport of *water* from a solution of *low* concentration to a *high* concentration	Transport of selected substances from region of *low* concentration to a *high* concentration against a concentration gradient
4	Occurs with or without a non-living *permeable* membrane	Either a living or non-living *semipermeable* membrane needed – cell membrane or Visking membrane	A *living* selective membrane is essential – lipoprotein plasma membrane
5	No cell energy required	No cell energy required	Cell energy from ATP required
Definitions			
	Transport of *gases* or *dissolved substances* in solution from a region of *high* concentration to a region of *low* concentration	Transport of *water* through a semipermeable membrane from a solution of *low* concentration to a solution of *high* concentration	Transport of a *substance* from *low* to *high* concentration regions, using energy from cell, through a living cell membrane

Transport of substances in *unicellular* organisms such as protozoa and algae will take place across the cell membrane and within the cell cytoplasm.

(i) Substances will pass through the *cell membrane* by diffusion, osmosis, active transport and filtration. In addition, unicellular animals allow substances to be taken into the cell by *phagocytosis* and *pinocytosis* (Sections 7.3 and 7.8).

(ii) Substances will be transported *within* the cell by diffusion and cytoplasmic streaming.

Simple *non-vascular multicellular* organisms, e.g. coelenterates and liverworts, will transport substances between adjacent cells by diffusion, osmosis and active transport.

9.3 TRANSPORT IN FLOWERING PLANTS: WATER ABSORPTION

The vascular tissues of a flowering plant consist of *xylem* and *phloem* present in the leaf, stem and root. Apart from the function of *anchoring* a plant in the soil, the roots also function for *absorption* of water and salts.

Experiment 9.1 *to examine young roots*

Procedure

(i) Germinate some cress seedlings and use a hand lens to examine the position of the root *hairs*.
(ii) Mount a small portion of a root with root hairs on a microscope slide. Add a drop of iodine solution stain. Cover with a coverslip and view through a light microscope.

Observations

The *root hairs* are located a short distance behind the *root cap*. Each root hair is composed of *one* cell containing cytoplasm and one cell *nucleus*.

Root hairs are short-lived outgrowths of a root *epidermis* that come into close contact with the film of *soil water* around the soil particles. Root hairs do not have a waterproof cuticle layer.

A root *surface* may have up to 500 root hairs per square centimetre. In this way the *surface area* of a root may be increased many times.

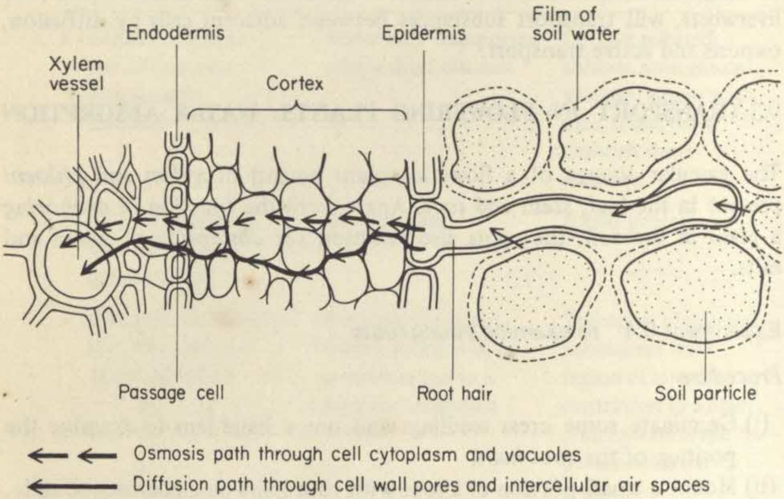
(a) Mechanism of water absorption

Soil water is a solution of *low* concentration, whilst the root hair vacuole sap is of a *higher* concentration. Water moves by osmosis from the soil through the root hair cell wall and cell membranes and *dilutes* the root hair cell sap (Fig. 9.1). It is believed that water is also able to move through the cell *wall* by *diffusion* through the tiny spaces between the cellulose fibres.

Water in the root hair is transported across the root cortex by three routes:

(i) *osmosis* across cell membranes of neighbouring cells along an *osmotic pressure* gradient;
(ii) *diffusion* through the cell wall cellulose fibre spaces;

fig 9.1 *pathway of water into and across a flowering plant root from the soil*


Film of soil water
Endodermis
Epidermis
Xylem vessel
Cortex
Passage cell
Root hair
Soil particle
Osmosis path through cell cytoplasm and vacuoles
Diffusion path through cell wall pores and intercellular air spaces

(iii) *diffusion* through the *intercellular* air spaces seen between cortex cells.

Water finally passes from the cortex cells into the xylem vessels.

Experiment 9.2 *to show movement of water through a tissue* (Fig. 9.2)

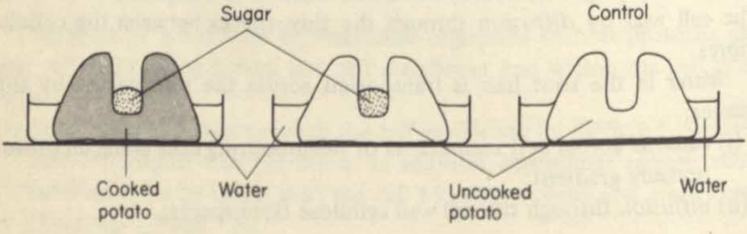
Procedure

(i) Prepare three equal sized and shaped peeled potatoes. Cut out a central core cavity in each.

(ii) Cook one potato for 3 min in boiling water.

(iii) Place all three potatoes in separate shallow dishes containing plain water.

fig 9.2 *to show osmosis in living tissue*



(iv) Sprinkle sugar crystals in the central core cavity of the boiled potato and *one* of the uncooked potatoes. The *control* will be without sugar.
(v) Leave for 12 h and observe any changes in appearance of the central core contents.

Observations

A sugar *solution* forms by drawing water from the tissues around the sugar crystals, water being provided by osmosis through *living* and not by the dead cooked potato tissue. Water levels in the dish have fallen due to transport across the living potato tissue.

(b) Root pressure

A well watered potted *Fuchsia* or vine plant has its stem cut back to soil level in the spring, and the stem cut end connected to a water gauge.

Sap oozes from the cut end of the stem and causes a change in liquid levels of the gauge. A *force* must be pushing water up from the roots; this is called *root pressure*. Certain plants can develop root pressures of up to 90 kPa.

9.4 FLOWERING PLANTS: TRANSPIRATION

Transpiration is the loss of water vapour by land plants, which occurs mainly through the open stomata of leaves by a process of evaporation.

Experiment 9.3 *to show that water is given off in transpiration*

Procedure

(i) Completely enclose the shoot system of a well watered potted plant, by means of a polythene bag firmly tied around the stem base at soil level.
(ii) Place aside for 24 h.
(iii) Observe the *condensation* of moisture inside the plastic bag. Remove the bag and collect a sample of the liquid and add it to white anhydrous copper(II) sulphate powder.

Observation

The liquid released by the plant shoot system is *water* as it is the only liquid able to turn white anhydrous copper(II) sulphate *blue*.

(a) Mechanism of transpiration

Water *evaporates* from the spongy mesophyll cells of the leaf into the leaf *air spaces* (Fig. 6.6) and the cell vacuole sap becomes more concentrated.

Water vapour leaves the leaf by *diffusion* through the open stomata.

A small amount, up to 10%, can diffuse through the leaf epidermis at places where the cuticle is thin or absent.

Osmosis occurs between neighbouring spongy mesophyll cells resulting in water transport along the osmotic gradient. The *xylem vessels* of the leaf vein provide more water to the spongy mesophyll cells.

Withdrawal of water from the *xylem* vessels continues through the leaf midrib vein, down the stem vascular bundle and into the *root* xylem vessels.

A pulling force called the *transpiration pull* acts upwards, drawing long continuous columns of water to the leaf.

The *root pressure* may also assist in this flow of water through the plant, called the *transpiration stream*.

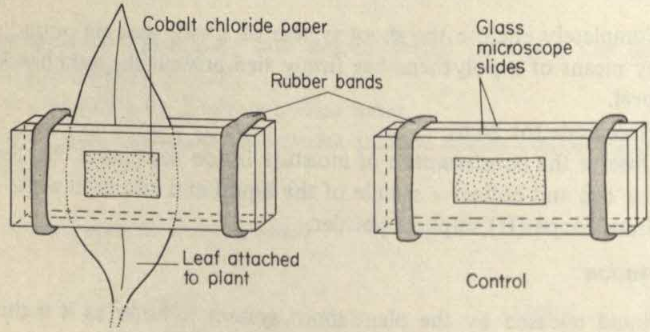
Experiment 9.4 *to compare water loss from leaf surfaces* (Fig. 9.3)

Procedure

(i) Place pieces of cobalt chloride or thiocyanate paper on the *upper* surface of a leaf attached to a plant.

(ii) Sandwich the leaf and paper between two *dry* microscope slides held in position by rubber bands. Attach a similar piece of cobalt chloride paper to the *lower* surface of another leaf on the same plant.

fig 9.3 *to show water loss from a dicotyledon leaf*



(iii) Prepare a *control* by sandwiching a cobalt chloride paper between two dry glass slides without a leaf.

(iv) Observe the test papers for the *time* it takes for them to turn from blue to a pink colour.

Observations

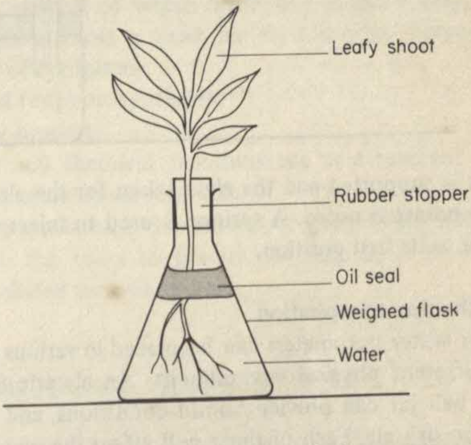
A leaf lower surface may have between 300 and 1000 stomata per square millimetre, whereas the upper surface may have few or no stomata. Test papers on the lower surface will change colour rapidly, whilst the papers on the upper surface and control are unaffected.

(b) Measurement of transpiration rate

(i) *Weight potometer*

This apparatus consists of a complete young plant supported in a flask of water (Fig. 9.4). An oil layer above the water acts as a seal to prevent water loss by evaporation.

fig 9.4 *a weight potometer*



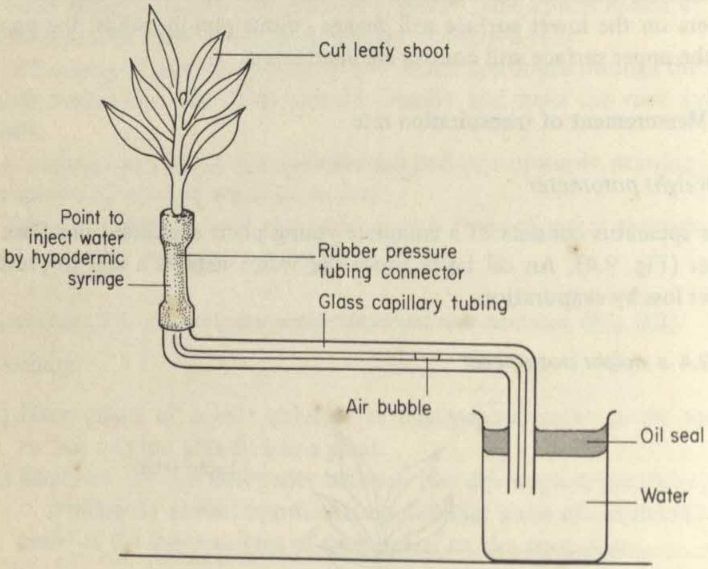
The apparatus is weighed at intervals, and changes in weight indicate water loss and therefore the *rate of transpiration*. The *control* consists of the same apparatus less the complete plant.

(ii) *Water potometer*

This is an apparatus which measures the rate of water *absorption*, by observing the rate at which an *air bubble* moves along a capillary tube (Fig. 9.5).

Leafy shoots are cut from a plant by submerging the stem *under* water, which prevents air locks forming in the xylem vessels. A glass capillary tube is connected to the cut stem by means of a rubber connecting tube. An air bubble is allowed to form in the capillary tube.

fig 9.5 *a water potometer for measuring rate of water uptake by a cut shoot*


Cut leafy shoot
Point to inject water by hypodermic syringe
Rubber pressure tubing connector
Glass capillary tubing
Air bubble
Oil seal
Water

The shoot is supported and the *time* taken for the air bubble to move between two points is noted. A syringe is used to inject water and return the air bubble to its first position.

(c) Factors affecting transpiration

The weight or water potometers can be placed in various surroundings, to simulate a different physical environment. An electric fan can generate a draught; a bell jar can provide humid conditions, and a radiant heater produces warm dry air. Each of these will affect the rate of transpiration.

Conditions which affect *evaporation* also affect transpiration but transpiration is *controlled* by stomata being open or closed.

(i) *Stomata*

In daylight the stomata of most species are open, and closed in darkness. Consequently, changes in light intensity will affect the transpiration rate.

(ii) *Wind*

Moving air removes water vapour from the leaf surface, allowing more to diffuse out of the leaf. Still air allows water vapour concentration to build up.

(iii) *Humidity*

The concentration of water vapour in air may vary from low concentration in *dry* air to higher concentration in *humid* air. Water vapour will only diffuse along the concentration gradient from a *high* concentration in the leaf to a *lower* concentration in the surrounding air.

(iv) *Temperature*

The concentration of water in air is related to temperature. Increases in temperature allow more water to evaporate; decrease in temperature prevents evaporation. Warm air holds more water than cold air.

(d) Function of transpiration

The land plant as a consequence of having a *large area* of shoot system, necessary for photosynthesis, must allow great volumes of water to flow through it by the transpiration stream.

Of the total amount of water circulating in the transpiration stream, only a very *small amount* is used for the following purposes in a plant:

(i) component of cytoplasm;
(ii) raw material for photosynthesis;
(iii) turgor body support;
(iv) solvent for cell chemical reactions and as a reactant in *hydrolysis*, chemical reactions involving water.

The transpiration stream is a means of transporting *soluble* inorganic substances from the roots to leaves, and may help in *cooling* a plant growing in overheated surroundings.

9.5 FLOWERING PLANTS: TRANSLOCATION

Translocation is the process of transport of *soluble* inorganic and organic substances within a plant.

(a) Translocation of inorganic substances

Carbon dioxide is transported by diffusion along concentration gradients from the air into the leaf air spaces.

Soil water is a dilute solution of ions of, for example, potassium, nitrate and phosphate. These ions move into the root hair by *active transport* against a concentration gradient from a low to a higher concentration. Energy is provided by aerobic respiration of the root hairs using oxygen from the soil *air*.

Movement of the inorganic substances across the root cortex is thought to be by *diffusion* by way of the cell walls.

Experiment 9.5 *to show uptake of substances by roots*

Procedure

(i) Stand complete white deadnettle or leek plants in a solution of red ink or eosin.
(ii) After 24 h cut transverse sections at different levels as in Experiment 3.4. Mount the sections on a microscope slide and view with a light microscope.
(iii) Cut a plant longitudinally and observe how far the colour extends up the stem using a hand lens.

Observations

Dissolved substances move into the root and in time are transported to the stem, leaves and even into petals. The red coloration appears only in the xylem vessels and none in the phloem.

(b) Radioactive tracers in translocation

Tomato plants are grown in a solution containing *phosphates* made from radioactive ^{32}P. The plants are removed at intervals and placed on a photographic film in a darkroom, and the film is developed. Dark areas appear on the film where radioactive ^{32}P has accumulated in the plant; this photographic picture is called an *autoradiograph.*

The radioactive isotope is a *tracer* and a means of showing the path taken by a substance, the phosphate ion, through the plant.

Transverse sections of the tomato stems are cut and placed on the photographic film. The *autoradiographs* show the presence of tracer *first* in the xylem vessels and then in the nearby phloem and parenchyma cells.

Radioactive tracers show that inorganic substances move *upwards* in the stem and root xylem vessels, and can also move *across* a stem. The phloem takes no part in the general upward translocation of inorganic materials.

(c) Translocation of organic substances

The products of *photosynthesis* of chloroplast-containing cells of leaves and stems are *organic substances* in the form of carbohydrate sugars.

Sucrose (cane sugar) is the carbohydrate translocated in flowering plants.

Sucrose containing radioactive ^{14}C (carbon) can be used as a *tracer* to follow the path of sugar translocation in tomato plants. Radioactive ^{14}C sucrose is applied to the tomato plant leaves after removing some of the cuticle.

Autoradiographs are taken at different times and they trace the path of sugar out of the leaf, *up* and *down* the stem to collect finally in the tomato *fruits*. Autoradiographs of transverse sections of the stem show radioactivity and ^{14}C sucrose in the *phloem* tissues which are therefore the channels of organic substance translocation.

Experiment 9.6 *to show the effect of removing phloem tissues from stems*

Procedure

(i) Cut fresh willow shoots under water.
(ii) Ring a shoot at a point below the leaves by cutting a complete ring of bark and removing the underlying phloem. Smear the 'ring' with soft

Table 9.2 *comparison of the channels of xylem and phloem*

	Xylem channel	*Phloem channel*
Location	In the *xylem vessels* thickened with lignin; these are *dead* cells without cytoplasm	In the *phloem* sieve tubes; these are *living* cells with a simple cytoplasm – no nucleus
Substances transported	Water and inorganic ions only	Soluble *inorganic* ions and *organic* materials, *sucrose* and amino acids
Direction of transport	*Upwards* from root to shoot system	*Upwards* and *downwards* between plant sources and sinks
Speed	Slow	Very rapid
Mechanism	Essentially a *passive physical* process involving osmosis, diffusion and evaporation. Oxygen-deprived and poisoned plants continue to transpire, showing that transpiration does not involve living cells	An *active biological* or *physiological* energy-consuming process using cell energy, ATP (dead phloem will not transport) – ringing experiment. Plants deprived of *oxygen* or 'poisoned' with *cyanide* are unable to translocate organic substances. Therefore process is one involving living cells
Definitions	*Transpiration* is the loss of water vapour from the *surface* of a plant. The upward movement of water in the xylem is the *transpiration stream*	*Translocation* is the transport within plants of all *soluble* substances

paraffin. Leave the *control* shoot unringed.

(iii) Insert both shoots in water, keeping the 'ring' above the water level. Leave aside for 2-3 weeks.

Observations

Adventitious roots will form on the cut end of the unringed shoot. The 'ringed' stem is unable to form roots as organic substances cannot be translocated downwards without *phloem* tissue. Swelling of the stem is seen immediately above the ring of the ringed stem, showing accumulation of organic substances.

Table 9.2 compares the transport channels of xylem and phloem.

9.6 TRANSPORT IN ANIMALS: MAMMAL BLOOD

Mammal blood is composed of *solid* components, the *blood cells* (Fig. 9.6) and a *liquid* component, the *blood plasma*. Blood is contained within the *vascular* system of *closed* blood vessels and the heart.

(a) Blood plasma

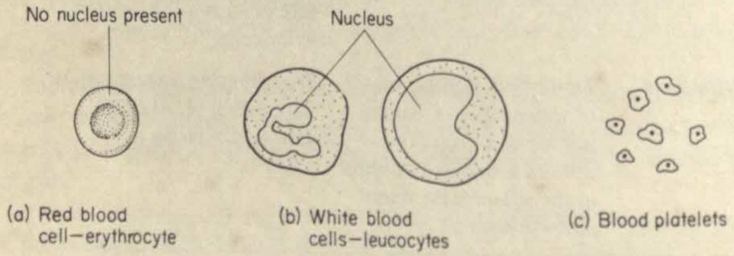
This is 92% water and contains the following soluble components:

(i) proteins 7%, hormones, albumins, globulin antibodies, and 0.3% fibrinogen; the latter when removed from plasma produces the fluid blood *serum*.
(ii) *food nutrients* – glucose, amino acids, fatty acids and glycerine (propanetriol).
(iii) *metabolic materials* – enzymes, vitamins, hormones, lactic acid, carbamide (urea) and uric acid.
(iv) *inorganic ions* of sodium, potassium, calcium, iron, chloride, sulphate and phosphate, and hydrogen carbonate radicals.

(b) Red blood cells

Red blood cells or erythrocytes are formed in the red bone marrow of

fig 9.6 *mammal blood cells*


No nucleus present
Nucleus
(a) Red blood cell—erythrocyte
(b) White blood cells—leucocytes
(c) Blood platelets

ribs, sternum and vertebrae. These are biconcave, disc-shaped cells without a nucleus, the cell cytoplasm being filled with the blood pigment *haemoglobin*. Following an average lifespan of 100 days, the red cells are broken down in the *liver* or *spleen*, the iron and protein material being recovered for further use, and part is excreted as a pigment in bile juice.

(c) White blood cells

White blood cells or leucocytes are of several kinds, differing in the structure and origin. All have a large prominent nucleus and are concerned with body defence, ingesting bacteria by *phagocytosis*, and in producing *antibodies*.

(d) Platelets

Platelets or thrombocytes are cell particles without a nucleus serving in body defence by *clotting* blood. Soluble fibrinogen is changed into a network of insoluble *fibrin*.

Experiment 9.7 *to show cellular components of blood*

Procedure

(i) Tie an elastic band around the last joint of a finger. Clean the skin with ethanol. Prick the skin with a *sterile* disposable lancet, and gently press the finger to exude a drop of blood.
(ii) Place the drop of blood on the end of a slide. Clean the finger with ethanol and remove the rubber band. Use the edge of another glass slide to smear the blood drop across the slide.
(iii) Leave to dry in air for 2 min and add two drops of Leishman's stain, and leave for 5 min. Wash off the excess stain in water. Leave to dry, and view through a light microscope.

Observations

The white blood cells can be easily distinguished from the other blood cells by their bright-staining nuclei.

9.7 MAMMALS: BLOOD FUNCTIONS

Blood functions are mainly for *transport*, for *protection* and in *homeostasis*.

(a) Respiration

Red blood cells have a high surface area/volume ratio and allow oxygen to diffuse rapidly into the red cell cytoplasm. Haemoglobin combines with oxygen to form unstable *oxyhaemoglobin*. This occurs in regions of *high* oxygen concentration in the lung:

$$\underset{\text{haemoglobin}}{Hb} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\text{oxyhaemoglobin}}{HbO_2}$$

Oxyhaemoglobin readily decomposes into oxygen and haemoglobin in regions of *low* oxygen concentration:

$$\underset{\text{oxyhaemoglobin}}{HbO_2} \longrightarrow \underset{\text{haemoglobin}}{Hb} + \underset{\text{oxygen}}{O_2}$$

Carbon dioxide is removed from cells mainly in the form of hydrogen carbonate ions which are soluble in blood plasma.

(b) Nutrition

Blood tissue fluid provides cells with a constant supply of *glucose* at a steady concentration of 0.1%, together with various minerals, vitamins and amino acids.

(c) Excretion

Excretory wastes mainly as urea (carbamide) are continually removed by the tissue fluid.

(d) Hormones

Chemical messengers or hormones control cell activities and diffuse rapidly through tissue fluid.

(e) Heat

Liver and muscle cells generate much heat. This is used to maintain a *constant* body temperature for cell chemical activity.

(f) Body defence

Antibodies are complex proteins made by white blood cells (lymphocytes), and provide immunity to certain diseases.

(g) pH

The blood plasma is maintained at a constant pH of 7.4 for efficient enzyme activity.

(h) Osmotic pressure

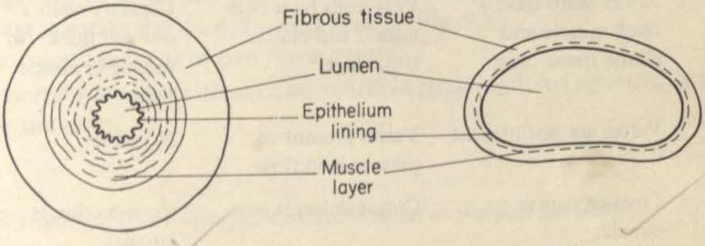
This is maintained at a constant level for body fluid and cell water control.

9.8 MAMMALS: BLOOD VESSELS

William Harvey (1578-1657), a physician, was the first to make studies of the blood circulation by experiment.

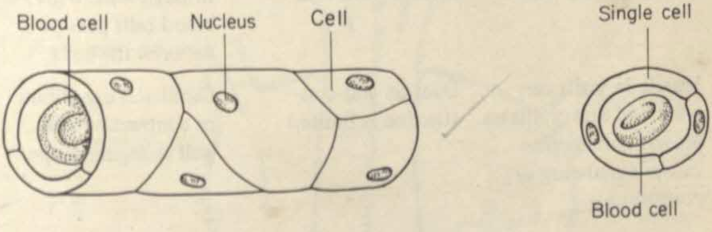
A simple plan of a mammal blood circulatory system is shown in Fig. 9.10. Blood is pumped by the *heart* along *arteries* to the *capillary* vessels and then returns to the heart by *veins* (Fig. 9.7). The same blood circulates in *one* direction, delivering oxygen and other substances at a high speed to the tissues.

fig 9.7 *internal structure of the three types of blood vessel*



(a) Artery

(b) Vein



(c) Capillary vessel

(a) Capillaries

These are small blood vessels with walls *one* cell in thickness; they receive blood from *arterioles* and deliver it to *venules*. Capillaries form extensive networks in organs such as the skin, lungs, liver, alimentary canal and muscles. Marcello Malpighi (1624-1694), a physician and anatomist, discovered capillary blood vessels.

(b) Arteries

Arteries carry blood under a *high* pressure *from* the heart. Artery walls are thick and muscular in order to withstand high blood pressure surges, detectable as a *pulse*. Muscle fibres in the artery walls can contract, causing *constriction* of the vessel, or can relax, causing it to *dilate*.

(c) Veins

Veins carry blood *towards* the heart under much lower blood pressure than in arteries. The walls are thinner, have less muscle fibres and are more

Table 9.3 *comparison of mammal blood vessels*

	Arteries	*Veins*	*Capillaries*
Structure			
1	Artery walls have a *thick* muscle and elastic tissue layer	Vein walls have *thin* muscle and elastic tissue layer	Capillary walls are *one* cell thick. *No* muscle or elastic tissue
2	Valves are *not* present	Valves present to prevent backflow	No valves
3	Cross-section is circular	Cross-section is oval	Cross-section is circular
4	Fluid and white blood cells cannot pass through artery wall	Fluid and white blood cells cannot pass through vein wall	Fluid *without* proteins *can* pass through wall. White blood cells pass out *between* the cells
5	Muscle in walls can *relax* and artery dilates. Muscle *contraction* causes narrowing or *constriction*	Dilation and constriction is limited	Capillaries can dilate or contract by cell wall changing shape
Blood composition and flow			
1	Flow is *away* from heart	Flow is *towards* the heart	Flow is from artery *to* vein
2	Oxygenated blood (except in pulmonary artery)	Deoxygenated blood (except in pulmonary vein)	Mixed oxygenated and deoxygenated blood
3	Rapid flow	Slow flow	*Very* slow flow
4	High pressure, 11 to 16 kPa	Low pressure, 1 to 2 kPa	*Very* low pressure
5	Pulse strong	No pulse	No pulse

elastic than arteries. Small pocket *valves* are located at intervals inside a vein to prevent backflow of blood.

Venous blood returns to the heart by means of the *muscle pump* due to the effect of the *skeletal* muscles contracting around the veins as occurs in exercise. This compresses the vein, driving the blood onwards.

Table 9.3 compares the structure and function of blood vessels in the mammal.

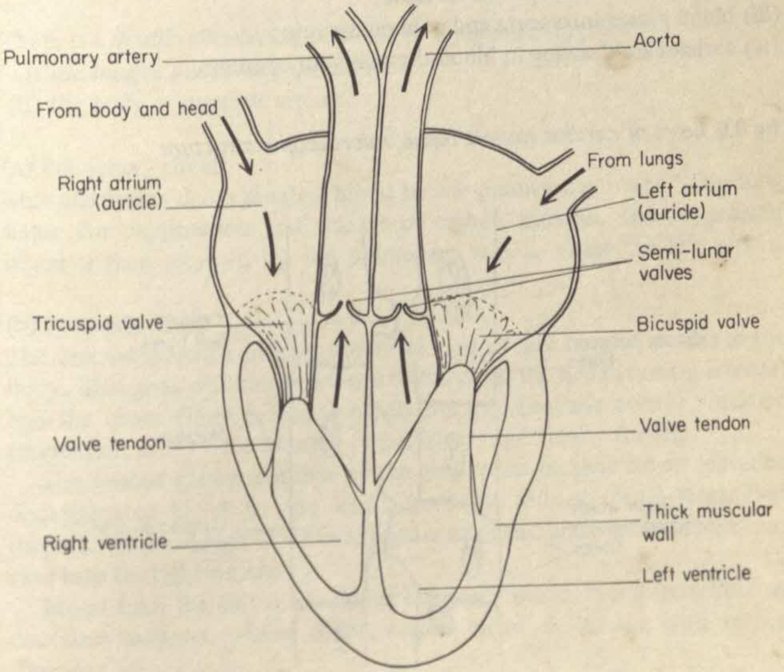
9.9 MAMMALS: THE HEART

A mammal heart is located in the *thorax* and is composed of four chambers, two *auricles* or *atria* and two *ventricles.* The left and right sides of the heart are separate and do not communicate (Fig. 9.8).

The heart functions as two *force pumps*:

(i) the *right* auricle (atrium) and ventricle pumping *deoxygenated* blood to the lungs;

fig 9.8 *mammal heart internal structure, seen in vertical section*



(ii) the *left* auricle (atrium) and ventricle pumping *oxygenated* blood to the body tissues.

Blood passes *twice* through the heart, once through the *right* side, and once through the *left* side, before being circulated to the body.

Heart muscle is called *cardiac* muscle (Fig. 9.9) and is different from skeletal muscle in working continuously and automatically without experiencing fatigue. The *coronary* artery supplies the heart tissues with their essential oxygen and nutrients.

(a) Heart or cardiac cycle

The heart muscles in the auricles and ventricles contract and relax simultaneously. Contraction of heart muscle is called *systole* and relaxation of heart muscle is called *diastole.*

When the auricles are contracting or are in systole, the ventricles are relaxing or are in diastole.

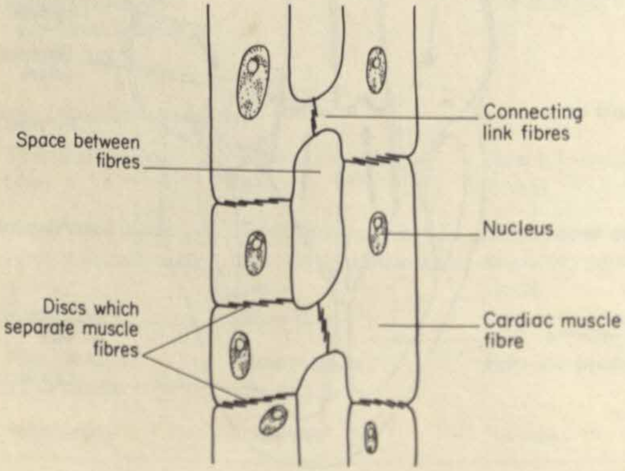
Auricular systole occurs when:

(i) auricle muscle contracts;
(ii) main vein openings close;
(iii) blood enters the ventricles past *open* tricuspid and bicuspid valves.

Ventricular systole occurs when:

(i) ventricle muscle contracts;
(ii) tricuspid and bicuspid valves *close*;
(iii) blood passes into aorta and pulmonary vein;
(iv) auricles are drawing in blood through vein openings.

fig 9.9 *heart or cardiac muscle tissue, microscopic structure*



The *heart beat* of 70 times a minute in a resting person is *heard* through the *stethoscope* as 'lub-dub'. This is the sound of the tricuspid and bicuspid valves closing, followed by the semi-lunar valves closing.

Experiment 9.8 *detection and recording of the pulse*

Procedure

(i) Place two or three fingers lightly on the skin close to the thumb base of another person's wrist.
(ii) Use a minute hand of a watch to record the number of beats per minute.
(iii) Ask the person to perform exercise in stepping up and down onto a chair for a certain time. Then record the pulse rate.

Observations

At systole blood flows through the *radial artery* in the wrist causing the artery wall to distend. At diastole the artery wall collapses. The total volume of blood in the body is circulated around the body and back to the heart in the time for 45 heart beats.

9.10 MAMMALS: BLOOD CIRCULATION

There is a *double circulation* of blood in a mammal (Fig. 9.10):
(i) the lung or *pulmonary* circuit, and
(ii) the body or *systemic* circuit.

(a) Pulmonary circuit

This distributes deoxygenated blood by the pulmonary *artery* to the lung tissue for *oxygenation* and release of carbon dioxide. The oxygenated blood is then returned by the pulmonary *vein* to enter the left auricle.

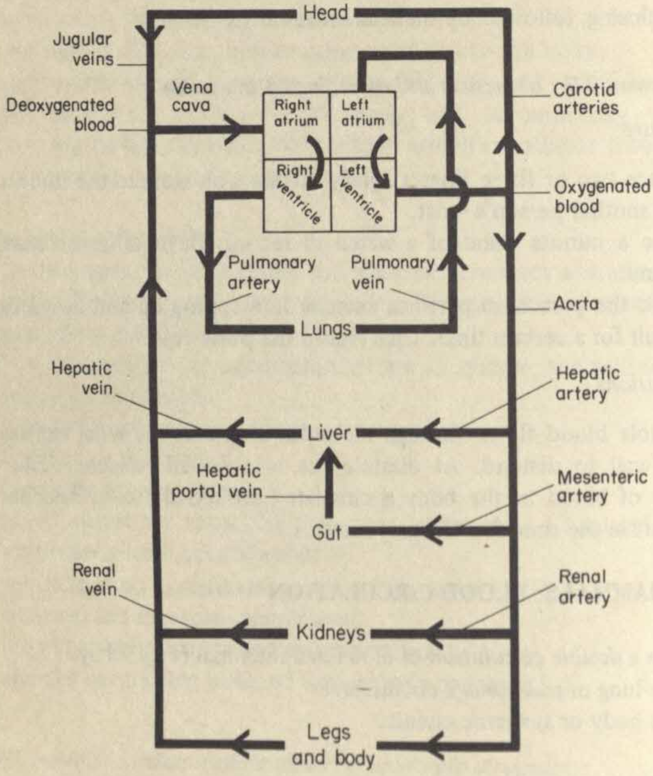
(b) Systemic circuit

The *arterial system* contains the *aorta*, one of the largest arteries in the body. This gives off branch arteries to the arms, the head (carotid arteries) and the chest. Other branches supply the liver (hepatic artery), intestine (mesenteric artery), the kidneys (renal artery) and finally the legs.

The *venous system* consists of the great veins or *vena cavae* delivering deoxygenated blood to the heart from the kidney (renal vein), liver (hepatic vein) and legs. The head (jugular vein) and arms link with the vena cava into the right auricle.

Blood from the kidneys is minus *excretory waste*, blood from the liver contains *nutrients*, whilst other venous blood is loaded with *carbon dioxide*.

fig 9.10 *the circulatory system of a mammal*



Between the gut and liver is the *hepatic portal* vein carrying venous blood from one capillary network to another. *Portal* blood vessels begin and end in *capillaries.*

(c) Blood pressure

Blood pressure can be measured *directly* by inserting a connection into the artery or vein and recording pressures on a *manometer* gauge. Blood pressure is measured *indirectly* with a *sphygmomanometer*, an inflatable cuff connected to a mercury manometer gauge.

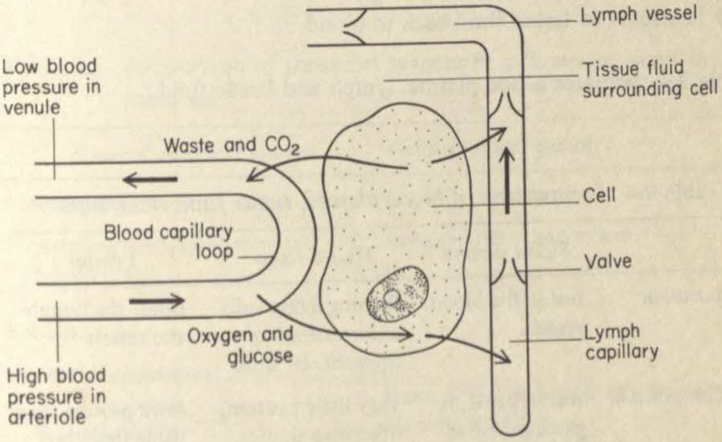
(i) *Diastolic blood pressure* in veins is 1 kPa, and in arteries 11 kPa.
(ii) *Systolic blood pressure* in veins is 2 kPa, and in arteries 16 kPa.

The surrounding air has an *atmospheric* pressure of 101 kPa, acting all over the body surface. The heart must produce a blood pressure in excess of this in order to circulate blood. The *absolute* blood pressure will be air pressure *plus* gauge pressure, or *absolute* systolic blood pressure will be 101 kPa plus 16 kPa, a total of 117 kPa.

9.11 MAMMALS: EXCHANGE AT THE CELLS

Blood capillary vessels are in close contact with cells. The blood pressure causes *fluid* to pass through the thin capillary vessel walls to become *tissue fluid* (Fig. 9.11).

fig 9.11 *tissue fluid formation*



Tissue fluid differs from blood *plasma* in containing little if any protein. White blood cells or leucocytes are able to squeeze through the space between adjacent capillary cell walls, and enter the tissue fluid.

After bathing the cells and supplying and removing various substances essential to cell *homeostasis* (Section 12.1), the fluid returns to the capillary vessels at the end close to the venule.

9.12 MAMMALS: LYMPH AND LYMPHATIC SYSTEM

A small amount of tissue fluid does not return to the blood capillary system, but is drained into *lymph capillaries*. These are blind-ended, fluid-filled tubes between cells. These lymph capillaries empty into large *lymph vessels* and then into main *lymph ducts* which deliver the lymph fluid into the *innominate* veins near the heart.

Lymph capillaries have highly *permeable* walls, allowing large molecules and bacteria to pass through which are unable to pass through *blood* capillary walls.

Lymph *nodes* or glands are swellings found at certain points in the lymphatic system, neck, armpits, groin and intestine wall. These serve to produce *lymphocytes*, which are similar to white blood cells in having a defensive phagocytic function. *Tonsils* and *adenoids* are lymphoid tissues with similar functions.

Movement of lymph in the lymphatic system is by means of the *muscle pump* mechanism similar to that operating on veins.

(a) Functions of lymph

(i) Body defence.
(ii) Lipid absorption by intestinal *villi*.
(iii) Transport of tissue fluid back to blood.

Table 9.4 compares blood plasma, lymph and tissue fluid.

Table 9.4 *comparison of blood plasma, tissue fluid and lymph*

	Blood plasma	*Tissue fluid*	*Lymph*
Location	Inside the blood vessels	Bathing living cells as *interstitial* or *intercellular* fluid	Inside the lymphatic vessels
Composition	Water, proteins glucose, amino acids, salts, enzymes and hormones. Oxygen is *present*	Very little protein, otherwise similar. Oxygen is *present*	*More* protein than tissue fluid, but *less* than blood plasma. More lipids, otherwise similar. *No* oxygen
Cells	Red, white and platelets	White (emerge between capillary cell walls)	White
Transport	*Blood pressure* forces fluid through capillary at artery end. *Osmosis* returns fluid at vein end of capillary	From capillary under *pressure* and return by *osmosis* to capillary. 90% returns to capillary, 10% drains to lymph	From tissue fluid by drainage under *pressure*. Lymph vessels empty into *veins*

9.13 STORAGE IN PLANTS AND ANIMALS

Food nutrients may be stored over short or long terms in most living organisms.

(a) Flowering plants

Nutrients synthesised by photosynthesis may be translocated to *growing regions* and used for constructing new tissues, or stored in *storage regions.*

(i) *Short-term* storage of carbohydrate is seen in starch formation in green leaves.

(ii) *Long-term* storage of carbohydrate as *starches* occurs in the parenchyma cells of perennating organs (Section 15.3). Fruit and seeds are also long-term storage organs.

Table 9.5 *comparison of transport systems in a flowering plant and a mammal*

Mammal transport system	*Plant transport system*
Vascular tissues	
Arteries, veins, capillaries and lymph vessels	Phloem sieve tubes and xylem vessels
System	
Double circulation: 1 to the *lungs* 2 to the *body* Arteries connect with veins by a *closed* capillary network. Lymph vessels *blind*-ended	Two: 1 *Transpiration* stream in xylem one-way, *upwards* 2 *Translocation* in phloem two-way, up and down Xylem and phloem tubes all *blind*-ended
Circulatory mechanism	
1 Blood, intercellular and lymph *fluids* – mainly water	1 Mainly *water* in xylem and phloem
2 Blood cells	2 No special transport cells
3 Physical action from heart and muscle 'pumps'. Powered by ATP energy	3 Physical action in xylem. Biological action using ATP energy in phloem
Substances transported	
Water and all water-soluble salts and organic materials, *dissolved* or *chemically* combined gases. Blood capillary walls are permeable for *lateral* transport. Arteries and veins are not	Water and most water-soluble salts and organic materials. Gases mainly dissolved. Xylem and phloem tubes are permeable for *lateral* transport

(b) Mammals

Surplus glucose, amino acids, fatty acids and glycerol (propanetriol) may undergo storage.

(i) *Short-term* storage is mainly as *glycogen* in liver and skeletal muscles, and this can be rapidly changed into glucose.

(ii) *Long-term* storage of lipids is found in the fat *depots* around the kidneys, heart, in muscles and under the skin. The *liver* (Section 12.2) is an important storage organ for vitamins A, D and B_{12}, and the mineral iron. Surplus amino acids are changed in the liver by *deamination* into glucose; this, with other surplus glucose, becomes *glycogen*.

Table 9.5 compares transport systems in the flowering plant with that of a mammal.

9.14 QUESTIONS

1 Describe how a flowering land plant absorbs water from the soil, transports it to the leaves, and eventually loses it into the air. Give three important uses of water in flowering plants. What conditions will *increase* the rate of water loss.

2 Briefly describe the importance of the following in transport of substances in flowering land plants: (a) diffusion; (b) osmosis; (c) evaporation; (d) active transport.

3 The following experimental results show water loss from a green plant over a period of one day (24 h). Draw a graph to show the water loss. Explain why the rate varies during the period and describe the apparatus used for the experiment.

Time (h)	9	13	17	21	24	3	7
Water loss (cm^3)	91	218	195	124	18	13	23

4 Describe the cellular and chemical composition of mammal blood. Indicate the functions of each blood component.

5 Give an illustrated account of the structure of a mammal heart. Indicate by arrows the direction of *oxygenated* blood flow. Compare the structure and function of arteries, veins and capillaries. What structure is common to all three blood vessels?

CHAPTER 10

RESPIRATION

10.1 INTRODUCTION

Respiration is a characteristic process of living organisms (Section 3.1) involving the *release of energy* by breakdown of chemical compounds.

The main energy-providing chemical compounds are the nutrients, carbohydrates, lipids and proteins, described in Section 8.3.

Respiration processes are of two main kinds:

(i) *External* respiration is a *physical* process, also called ventilation or breathing, concerned with gas exchange in air-breathing organisms.

(ii) *Internal* respiration is a *biochemical* process taking place inside living *cells* in either the *cytoplasm* or cell organelle, the *mitochondria* (Section 3.4). This process, also called *cell respiration*, will be described in the first half of this chapter.

10.2 ENERGY RELEASE IN LIVING CELLS

Glucose, $C_6H_{12}O_6$, is the main *respiratory substrate* or substance which is broken down or *respired* in living organisms to yield energy. Energy can exist in different forms (see Section 5.8); the main forms of energy in a respiring cell are *heat* and *chemical* energy.

In the living cell a *series* of *enzyme*-controlled chemical changes *slowly* release the potential energy from glucose.

Approximately 60% of the released energy is in the form of *heat*, whilst about 40% is *chemical* energy in the form of an energy-rich compound called *adenosine triphosphate* or ATP. This was discovered by the biochemist Karl Lohmann (born 1898).

ATP can be moved about inside the cell and release kinetic energy for various cell *activities*, at the same time forming adenosine diphosphate or ADP. The amount of energy released from *one molecule* of ATP is 33 kJ:

$$\underset{\substack{\text{adenosine}\\\text{triphosphate}}}{\text{ATP}} \longrightarrow \underset{\substack{\text{adenosine}\\\text{diphosphate}}}{\text{ADP}} + 33\text{ kJ energy}$$

ATP is therefore a form of *stored* chemical energy able to provide energy *rapidly* to a living cell.

Experiment 10.1 *to show that respiration produces heat* (Fig. 10.1)

Procedure

(i) Prepare sufficient pea seeds, wheat or barley grains, by soaking in water 24 h. Wash in 10% formalin (methanal) or 10% sodium hypochlorite to sterilise.

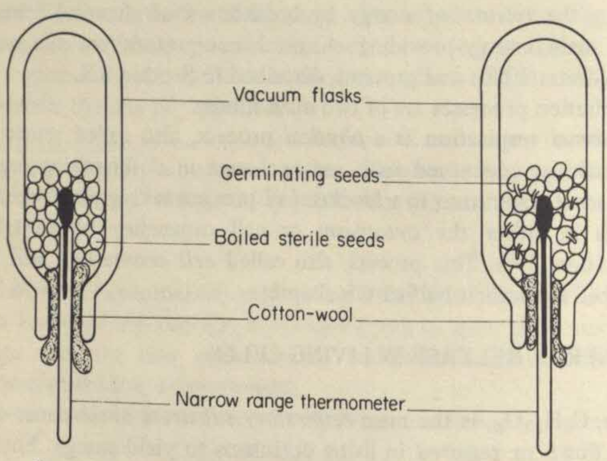
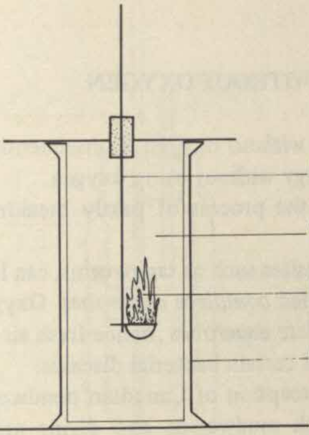


fig 10.1 *to show that heat is a product of respiration from germinating seeds*

(ii) Prepare *control* by boiling the seed or grain for 5 min, then sterilise.
(iii) Pack the experiment vacuum flask with soaked live peas or grain. Pack the *control* vacuum flask with dead peas or grain. Plug the flask mouth with cotton-wool surrounding a narrow-range thermometer.

(a) Chemical combustion of glucose

Dry powdered glucose can be *burnt* in the laboratory in a chemical process of combustion or *oxidation* (see Section 4.10). Oxygen, present in air to the extent of 20% by volume, is needed for the process (Fig. 10.2). The fig 10.2 *to demonstrate the chemical combustion of a sugar*



chemical combustion of glucose can be shown in the following chemical equation:

$C_6H_{12}O_6$	+ $6O_2$	$\longrightarrow 6CO_2$	+ $6H_2O$	+ 2800 kJ energy
glucose	oxygen	carbon dioxide	water	

One mole (molecular weight in grammes) or 180 g glucose will produce 2800 kJ of heat energy; this is measured by a calorimeter (see Section 8.3).

(b) Features of chemical combustion of glucose

(i) *Occurrence*

Occurs in a test-tube reaction taking place outside of living cells; the reactant in a dry, *solid* form needs a good supply of oxygen *gas*.

(ii) *Mechanism*

Heat is needed to *start* the reaction which proceeds very *rapidly* with production of a *flame*. Chemical combination occurs.

Reaction can be controlled by increasing the oxygen *concentration*, or by altering the supply of air. Oxygen or air *deprival* stops the process.

(iii) *Energy*

All the energy produced is in the form of *heat*, released in one lot.

(iv) *Products*

The products are both gaseous.

10.3 CELL RESPIRATION WITHOUT OXYGEN

The Earth in its infancy was *without* oxygen. Consequently, the first living organisms had to obtain energy without using oxygen.

Anaerobic respiration is the process of partly breaking down glucose without using oxygen.

Certain bacteria, and parasites such as tapeworms, can live continuously without oxygen and are called *complete anaerobes.* Oxygen is poisonous to bacteria which are *complete anaerobes*; hence fresh air and oxygen-rich chemicals are used to combat certain bacterial diseases.

Green plants, with the exception of Canadian pondweed (*Elodea*) and certain yeasts, together with mudworms and diving mammals (such as whales and seals) are *partial anaerobes* able to live for *short* periods completely without oxygen. Mammal skeletal muscle cells can also respire anaerobically for *short* periods.

(a) Anaerobic respiration in plants

When plants respire anaerobically the glucose is broken down to produce *two* products, ethanol (ethyl alcohol) and carbon dioxide gas. The reaction can be summarised as follows:

$$\underset{\text{glucose}}{C_6H_{12}O_6} \longrightarrow \underset{\text{ethanol}}{2C_2H_5OH} + \underset{\text{carbon dioxide}}{2CO_2} + 210\text{ kJ energy}$$

$$\begin{tikzcd} & 210\text{ kJ energy} \arrow[dl] \arrow[dr] & \\ \underset{\text{heat}}{70\%} & & \underset{\text{energy}}{30\%\text{ ATP}} \end{tikzcd}$$

Experiment 10.2 *to show anaerobic respiration in yeast* (Fig. 10.3)

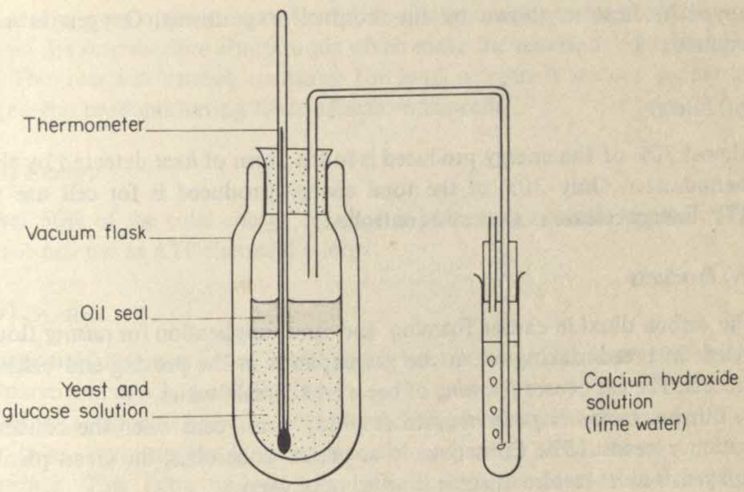
Procedure

(i) Place a boiled and cooled solution of 10% glucose in a vacuum flask. Stir 3 g of baker's yeast into a thin cream with a little water and add to the glucose solution. Add liquid paraffin oil to form a layer of *air-excluding* oil.

(ii) Insert a stopper supporting a narrow-range thermometer dipping into the yeast-glucose solution, and a delivery tube leading to a test tube of either hydrogen carbonate indicator or clear calcium hydroxide solution.

(iii) Set up a *control* made from a boiled and cooled suspension of yeast in 10% glucose solution.

fig 10.3 *to show anaerobic respiration of yeast,* Saccharomyces *sp.*


Thermometer
Vacuum flask
Oil seal
Yeast and glucose solution
Calcium hydroxide solution (lime water)

Observations

A rise in temperature is observed in the experiment flask, showing release of heat energy. Carbon dioxide gas is evolved causing the calcium hydroxide to turn cloudy and hydrogen carbonate indicator to turn from red to yellow.

Further procedure

(iv) Filter a sample of the yeast-glucose solution, observing its odour.
(v) Distil a portion of the clear liquid and collect some of the first distillate.
(vi) Observe the smell of the distillate. Place in a shallow dish and ignite with a lighted taper.

Observation

Distillation produces ethanol solution; this is flammable and burns releasing heat and light energy.

(b) Features of anaerobic respiration in plants

(i) *Occurrence*

Anaerobic respiration occurs with glucose *dissolved* in solution in the cell *cytoplasm.*

(ii) *Mechanism*

The reaction occurs *slowly*, and is controlled by *enzymes* which are destroyed by heat as shown by the 'control' experiment. Oxygen is *not* required.

(iii) *Energy*

Almost 70% of the energy produced is in the form of *heat* detected by the thermometer. Only 30% of the total energy produced is for cell use as ATP. Energy release is slow and controlled.

(iv) *Products*

The carbon dioxide causes foaming, and finds application for *raising* flour dough in bread-making when the gas expands in the proving and baking process. The gas causes *foaming* of beers and certain wines.

Ethanol becomes *poisonous* to respiring yeast cells when the concentration exceeds 15%. Consequently as partial anaerobes, the green plants and yeasts must respire at some time using oxygen.

Ethanol is a substance able to release *further* energy by *oxidation* (see Sections 8.3 and 8.8). Alcoholic beverages are made using different species of yeasts in solutions of sugars from different sources – barley, potatoes, grape juice, etc.

(c) Anaerobic respiration in animals

When animal cells, particularly *skeletal muscle* cells, respire anaerobically, the glucose is broken down to produce *one* product, 2-hydroxypropanoic or lactic acid. *No* carbon dioxide is produced.

The chemical process can be summarised as follows:

$$\begin{tikzcd}[column sep=small]
\underset{\text{glucose}}{C_6H_{12}O_6} \arrow[r] & \underset{\substack{\text{lactic}\\ \text{(2-hydroxypropanoic)}\\ \text{acid}}}{2CH_3.CH.OH.COOH} & + & \text{150 kJ energy} \arrow[dl] \arrow[dr] & \\
& & \substack{55\%\\ \text{heat}\\ \text{energy}} & & \substack{45\%\\ \text{ATP}\\ \text{energy}}
\end{tikzcd}$$

(d) Features of anaerobic respiration in animals

(i) *Occurrence*

Anaerobic respiration occurs with glucose in solution in the cell cytoplasm.

(ii) *Mechanism*

It is a *slow* process controlled by *enzymes*. It is important to note that the *equation* given opposite shows only the *reactants* and *products*; it does not show the *intermediate* compounds which make the reactions complex.

The reaction cannot continue for long; oxygen is needed sooner or later, the products having *toxic* effects on the cells.

(iii) *Energy*

Over 50% of the total energy released is *heat* energy, whilst less than 50% is for cell use as ATP chemical energy.

(iv) *Product*

Lactic acid increases in concentration in muscle tissue and causes *poisoning*, experienced as aches, and fatigue.

Resting allows the lactic acid to be changed back into *glucose*. In order to do so, *extra oxygen* is taken into the body after strenuous exercise by *panting*. This extra oxygen pays off the *oxygen debt* arising through muscles respiring anaerobically.

10.4 CELL RESPIRATION WITH OXYGEN

Oxygen has accumulated in the air to the extent of 20% by volume mainly as a byproduct of *photosynthesis* in green plants. As a result, living organisms have developed *aerobic respiration* or the use of oxygen to break down glucose *completely* into carbon dioxide and water.

The chemical reaction is *summarised* as follows, and is similar to that for combustion of glucose (Section 10.2):

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \longrightarrow 6CO_2 + 6H_2O + \underset{\substack{\swarrow \qquad\qquad \searrow \\ 55\% \qquad\qquad 45\% \\ \text{heat} \qquad\qquad \text{ATP} \\ \text{energy} \qquad\qquad \text{energy}}}{2800 \text{ kJ energy}}$$

(a) Features of aerobic respiration

(i) *Occurrence*

Glucose dissolved in solution is brought to the *mitochondria* of the plant and animal cells.

(ii) *Mechanism*

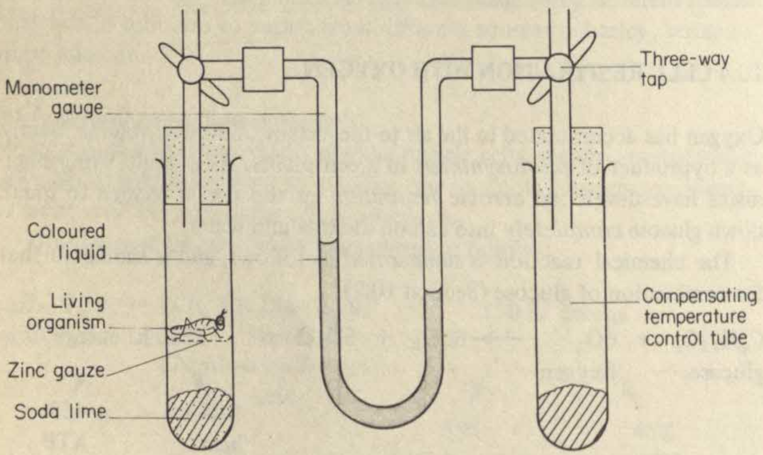
The process of energy release is slow and passes through many *intermediate* stages. The first stages are partly similar to anaerobic respiration, and *do not* require oxygen. The later stages require a continual supply of oxygen, and pass through a complex repeated *cycle* known as the citric acid or *Krebs cycle*. All stages are controlled by enzymes (see Experiment 4.3), and take place on the mitochondria. Sir Hans Krebs (1900-1981), a biochemist, was the discoverer of the citric acid cycle in mitochondria.

Experiment 10.3 *to show that oxygen is taken up during aerobic respiration* (Fig. 10.4)

Procedure

(i) The apparatus shown in Fig. 10.4 is a *respirometer*. Soda lime *absorbs* carbon dioxide, leaving nitrogen and oxygen gas in the air.

fig 10.4 *a respirometer apparatus*



(ii) Respiring organisms such as earthworms, insects or *sterile* germinating seedlings are placed in one tube supported by the zinc gauze platform.
(iii) Liquid levels in the manometer gauge are equalised by means of opening the three-way taps.
(iv) A separate *control* apparatus is set up containing non-living items, e.g. glass marbles or sterile dead seedlings.

Observations

A change in the air volume inside the apparatus is shown by the manometer. This indicates that the gas oxygen is consumed; nitrogen is inert and takes no part in cell respiration. Table 10.1 shows oxygen consumption of various animals.

Table 10.1 *oxygen consumption of different animals*

Earthworm	0.06 cm^3/g h
Butterfly (resting)	0.6 cm^3/g h
Maggot	1.3 cm^3/g h
Frog	1.5 cm^3/g h
Mouse (resting)	2.5 cm^3/g h

The *respirometer* can be used to determine the amount of oxygen measured in cm^3 taken up for each gramme of body weight per hour.

(1) Rate of respiration

The oxygen consumption rate is equal to the *rate of respiration*, and this in turn is a measure of the *metabolic rate*. Animals have much higher rates of respiration or metabolic rates compared to green plants.

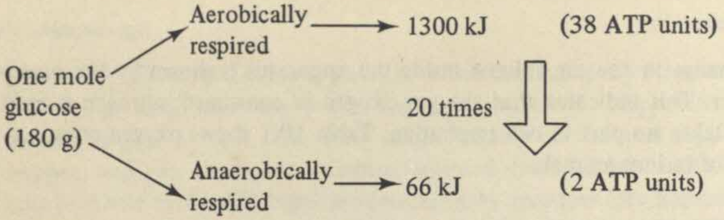
(2) Temperature effects on anaerobic respiration

Respiration involves the use of *enzymes*. Enzyme activity is affected by temperature change. At low temperatures of below 5°C, enzymes are inactive. They show optimum activity at about 30°C. At higher temperature, the enzymes are denatured and destroyed.

(iii) *Energy*

The total amount of energy, 2800 kJ, released by respiration of one mole, or 180 g, of glucose, is approximately 50% in the form of *heat* energy and 50% as ATP for *cell* use.

In comparison to anaerobic respiration, it is seen that aerobic respiration provides *twenty* times the amount of energy provided by anaerobic respiration of an equal quantity of glucose:



The *heat* energy released is evident in living man where the body temperature reaches 40°C.

(iv) *Products*

(1) Water

Although water is an important product of respiration, it is difficult to devise a simple experiment showing its formation during aerobic respiration. Plants release water as part of the *transpiration stream* (Section 9.4). Animals can release water by *evaporation* from body organs; this water may be part of the intake in food and drink.

Water which is strictly the product of aerobic respiration is called *metabolic water* (Section 8.12).

(2) Carbon dioxide

Carbon dioxide is a *poisonous* substance if allowed to accumulate in living cells. It is therefore removed by efficient *external* respiration methods, described in this chapter.

Experiment 10.4 ***to show that carbon dioxide is produced during aerobic respiration of small organisms*** (Fig. 10.4)

Procedure

(i) Rinse the respirometer test tubes with distilled water and partly fill with either red hydrogen carbonate indicator or clear calcium hydroxide solution.
(ii) Support one of the following on the perforated zinc platform: earthworm, insect, green leaf, piece of fresh root, flower bud, sterile seedlings.
(iii) Prepare a *control* using sterile dead material or a glass marble.
(iv) When using green plant material, black out the tube with metal foil.
(v) Leave apparatus to react for 1 h.

Observations

Respiring organisms produce carbon dioxide, causing colour changes of calcium hydroxide and hydrogen carbonate indicators. Aerobic and anaerobic respiration both yield carbon dioxide; anaerobic respiration in animal cells does not.

10.5 EXTERNAL RESPIRATION

Aerobic respiration requires a continuous flow of oxygen into cells with rapid removal of carbon dioxide from cells. This is called *external respiration*, and may involve two processes depending on the type of organism:

(i) *ventilation*, or breathing, the process of moving oxygen and carbon dioxide to and from the *respiratory surface* of the skin, gills or lungs;
(ii) *gaseous exchange*, the process by which oxygen and carbon dioxide pass *through* the respiratory *membrane* into and out of the cell.

(a) Conditions needed for external respiration

(i) *Oxygen supply*

Oxygen is available *dissolved* in sea or fresh water, or in its *gaseous* form in air. There is 25 times more oxygen in air than is dissolved in an *equal volume* of sea water (Table 10.2). Aquatic animals must transport great volumes of water to their respiratory surfaces.

Table 10.2 *summary of dissolved substances in fresh water and sea water compared with air*

Component	*Sea water* (%)	*Fresh water* (%)	*Air* (%)
Oxygen gas	0.85	1.03	20
Nitrogen gas	1.45	1.90	79
Salts, mainly sodium chloride	3.5	traces	nil
Water	94	97	varies to about 6%

(ii) *Diffusion*

This is the movement of substances in air or water. The rate of diffusion of oxygen in air is 100 000 times the diffusion rate of oxygen in water.

Oxygen and carbon dioxide will diffuse very *slowly* in cell fluid, compared to rapid diffusion in body air *spaces* of lungs and tracheae.

(iii) *Moisture*

Moisture in the form of water or mucus on the respiratory surface is needed to *dissolve* the gases before they can diffuse through the membrane.

(iv) *Permeable membranes*

Permeable thin membranes or skins allow rapid diffusion compared to non-permeable scaly skins.

(v) *Surface area*

The surface area of the respiratory membrane must be as large as possible to allow rapid diffusion.

(b) Body size in respiration

Amoeba surface area is 2.5 mm^2 and body volume 0.1 mm^3, whilst man has a surface area of 1.8 m^2 and a body volume of 80 litres.

Surface area/volume ratios are shown as follows:

$$\textit{Amoeba} \qquad \frac{2.5 \text{ mm}^2}{0.1 \text{ mm}^3} = 25$$

$$\text{Man} \qquad \frac{18\,000 \text{ cm}^2}{80\,000 \text{ cm}^3} = 0.225$$

Comparing these ratios it is seen that *Amoeba* has 25/0.225 or 111 times more surface area/body volume than man.

As organisms *increase* in size, the body surface area for gas exchange purposes becomes *less*. As a result, larger organisms develop special respiratory surfaces or *organs.*

In small organisms the diffusing oxygen and carbon dioxide need only travel a short *distance* to reach the centre of the unicellular organism or the innermost cell of multicellular organisms.

(c) Respiration in air and water

(i) *Aquatic organisms*

These have delicate respiratory organs, such as gills, *supported* and kept *moist* by the surrounding water. Since large volumes of viscous water must reach the respiratory organs, it does so in a *one-way* flow.

(ii) *Air-breathing organisms*

These have the delicate respiratory organs protected *inside* the body, and kept moist by *mucus* which prevents the respiratory surface from drying out by evaporation.

Since air is 100 times less viscous than water and contains more oxygen per unit volume, a *two-way* flow of air operates in the respiratory organs of air-breathing organisms.

10.6 EXTERNAL RESPIRATION IN SMALL ANIMALS

The cell surface in *Amoeba* and body surface of *Hydra* function as the respiratory surface. The high surface area/volume ratio permits simple diffusion of respiratory gases over short diffusion *distances*.

Earthworms have an epidermis layer one cell in thickness, kept moist by mucus secretion. The respiratory gases diffuse over a short distance to enter the blood *gas transport* system. Oxygen, due to its very *low* solubility, combines chemically with the blood haemoglobin.

10.7 EXTERNAL RESPIRATION IN INSECTS

(a) Respiratory system

The respiratory system is a *tracheal* system or network of interconnecting air-filled tubes–called *tracheae* delivering air directly to the body tissue cells.

Tracheae are lined with *cuticle* which is continuous with the outer epidermis as a waterproof, non-permeable outer layer (Fig. 10.5).

The tracheae have spiral rings called *taenidia* which serve to keep the tubes open. Air enters the tracheal system by *spiracle* pores, a pair usually being located on the sides of each segment of the thorax and abdomen.

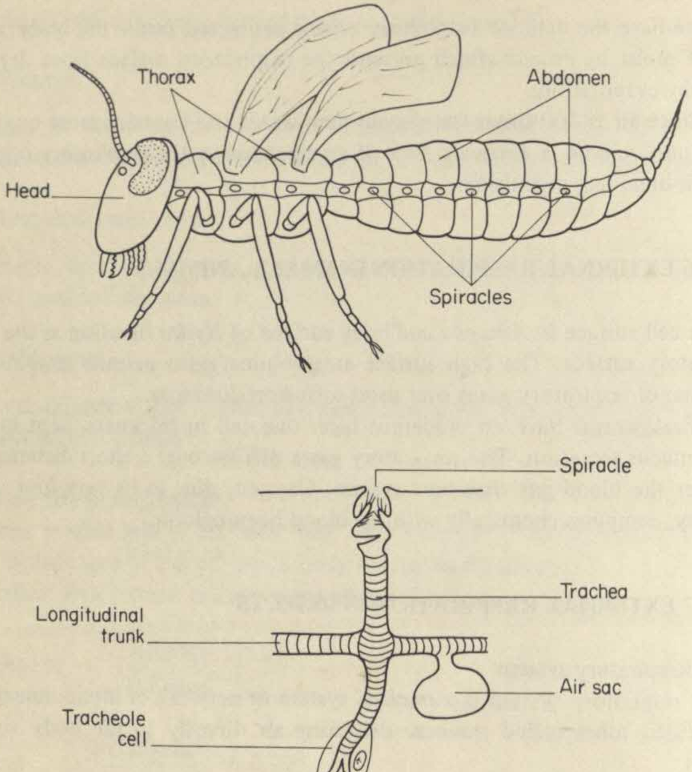
A spiracle may have a *pit* or atrium with hairs acting as filters, together with a muscular valve, regulating the spiracle opening and closure. This controls water loss from internal body tissues.

(b) Ventilation

Ventilation is achieved by contraction and relaxation of abdominal muscles; this results in a rhythmic 'pumping' of air into and out of the tracheae. Some insects have flexible *air sacs* connected to the tracheae and these may help in air flow.

Cockroaches, beetles and locusts show a *flattening* of the abdomen, whilst bees, flies and wasps show a *telescoping* of the abdomen in their ventilation movements.

fig 10.5 *general arrangement of the respiratory system of an insect*



(c) Gas exchange

Gas exchange takes place in the unthickened *tracheoles* which are permeable to gases and are filled with a *fluid* in contact with the body tissue. The fluid disappears when an insect is active, thus allowing respiratory gases to enter and leave the tissue rapidly. When the insect is inactive the fluid returns. Gases are not transported in the blood of insects.

10.8 EXTERNAL RESPIRATION IN A BONY FISH

(a) Respiratory system

The respiratory system of a bony fish, e.g. cod, whiting or herring, consists of *gills* in an *opercular cavity* protected by an *operculum* gill cover. The gill slits connect the *buccal cavity* with the opercular cavity.

A gill is made up of the gill *arch* which supports the two rows of gill *filaments*. Each gill filament has rows of gill *flaps* with a blood capillary network.

Experiment 10.5 *dissection of a fish head*

Procedure

(i) Obtain a large cod's head.
(ii) Remove the operculum with scissors and examine the gill structure with a hand lens.

Observation

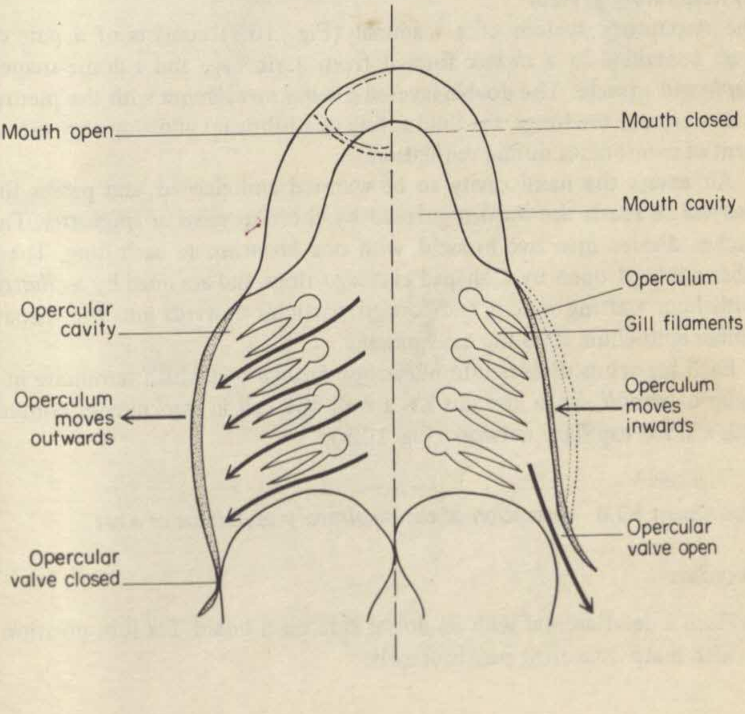
Note how the gill filaments cling together, reducing the gill surface area.

(b) Ventilation

Ventilation movements in a bony fish are shown in Fig. 10.6.

Inspiration commences by water being drawn into the buccal cavity by lowering the mouth floor. The outward movement of the operculum sucks

fig 10.6 *ventilation movements in a bony fish*



water into the operculum cavity; this is aided by the raising of the mouth floor. Surrounding water pressure keeps the opercular *valves* closed.

Expiration occurs by the *inward* movement of the operculum and *opening* of the opercular valves. This causes the buccal cavity to contract in volume and drive out water through the open opercular valves.

(c) Gas exchange

Gaseous exchange takes place on the gill *flaps* or secondary lamellae which provide a respiratory surface 10 times the fish's body surface area. The gill flap walls are *one* cell in thickness and separated by the capillary cell wall thickness from the blood.

Water passing over the gill flaps does so in the *opposite* direction to the blood flow in the capillary vessels. This is a very efficient *counterflow* system extracting more than 80% of the available oxygen in the water.

Haemoglobin in the blood transports oxygen to all parts of the body. This, together with the counterflow at the gills, maintains a diffusion *gradient* of oxygen in the blood.

10.9 EXTERNAL RESPIRATION IN MAN AND MAMMALS

(a) Respiratory system

The respiratory system of a mammal (Fig. 10.7) consists of a pair of *lungs* contained in a *thorax* formed from a rib cage and a dome-shaped *diaphragm* muscle. The double-layered *pleural membranes* with the pleural *fluid* surround the lungs, the fluid acting as a lubricant allowing easy movement of membranes during ventilation.

Air enters the nasal cavity to be warmed and cleaned, and passes the *pharynx* to reach the *trachea* guarded by the flap valve or *epiglottis*. The trachea divides into two bronchi, with one *bronchus* to each lung. These tubes are kept open by C-shaped cartilage rings and are lined by a *ciliated* epithelium wafting mucus and foreign particles upwards into the throat. Similar epithelium lines the nasal passage.

Each bronchus divides into numerous *bronchioles* which terminate in a group of *alveoli*. Each alveolus has a wall one cell in thickness in contact with a blood capillary network (Fig. 10.8).

Experiment 10.6 *dissection of the respiratory apparatus of a rat*

Procedure

(i) Place a dead animal with its dorsal side on a board. Fix it in position with sharp dissecting points or awls.

fig 10.7 *the respiratory system of man*

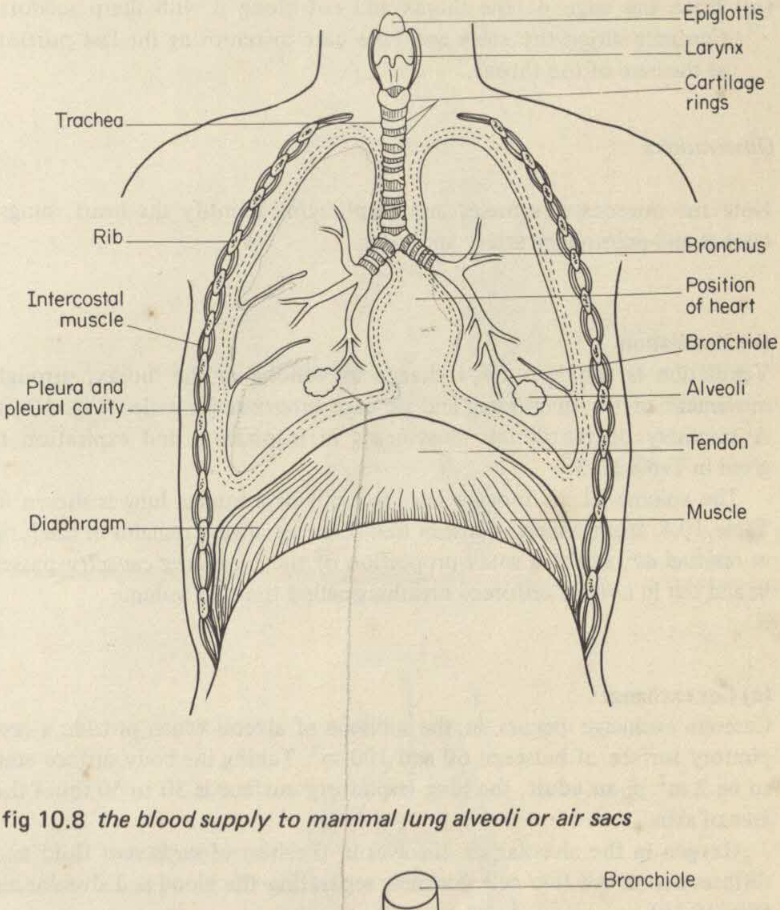
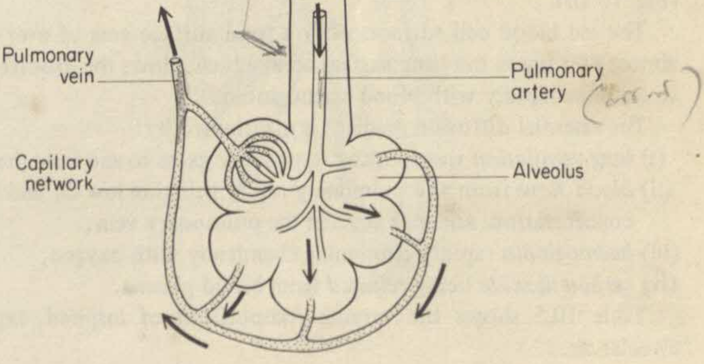


fig 10.8 *the blood supply to mammal lung alveoli or air sacs*



([illegible])

(ii) Using a sharp scalpel, cut through the skin along the midline of the abdomen and up the neck. Pin back the skin on each side.

(iii) Trace the edge of the thorax and cut along it with sharp scissors. Continue along the sides and take care in removing the last portion at the base of the throat.

Observations

Note the intercostal muscles and diaphragm. Identify the heart, lungs, trachea and pulmonary artery and veins.

(b) Ventilation

Ventilation is achieved by a change in volume of the thorax, through movement of the diaphragm and rib cage *intercostal* muscles (Fig. 10.9). A summary of ventilation movements in inspiration and expiration is given in Table 10.3.

The volume of air moving into and out of a human lung is shown in Table 10.4, from which it is seen that some air always remains in the lung as *residual air*, whilst a small proportion of the *total lung capacity* passes in and out in normal unforced breathing called the *tidal* volume.

(c) Gas exchange

Gaseous exchange occurs in the millions of alveoli which provide a respiratory surface of between 60 and 100 m^2. Taking the body surface area to be 2 m^2 in an adult, the lung respiratory surface is 30 to 50 times the area of skin.

Oxygen in the alveolar air dissolves in the film of *surfactant* fluid and diffuses across the two cell thickness separating the blood and alveolar air (Fig. 10.10).

The red blood cell surfaces offer a total surface area of over 4000 m^2, almost 400 times the lung surface area, which allows the dissolved oxygen to combine rapidly with blood haemoglobin.

The essential diffusion gradient is maintained by:

(i) *lung ventilation* transporting respiratory gases to and from the alveolus;

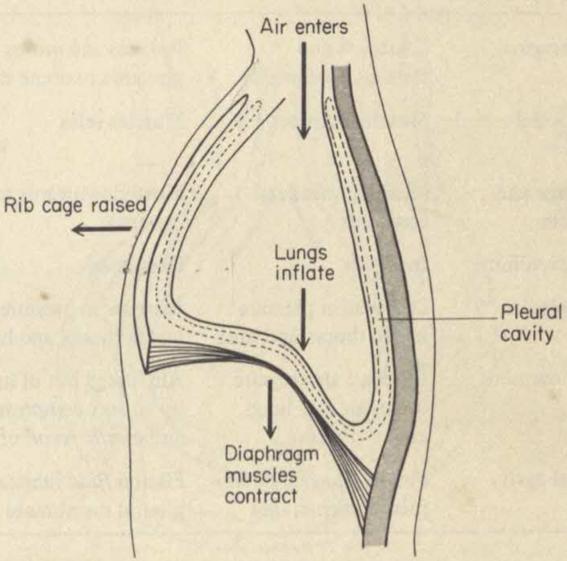
(ii) *blood flow* from the pulmonary artery bringing low O_2 and high CO_2 concentration, and vice versa in the pulmonary vein;

(iii) *haemoglobin* rapidly combining chemically with oxygen;

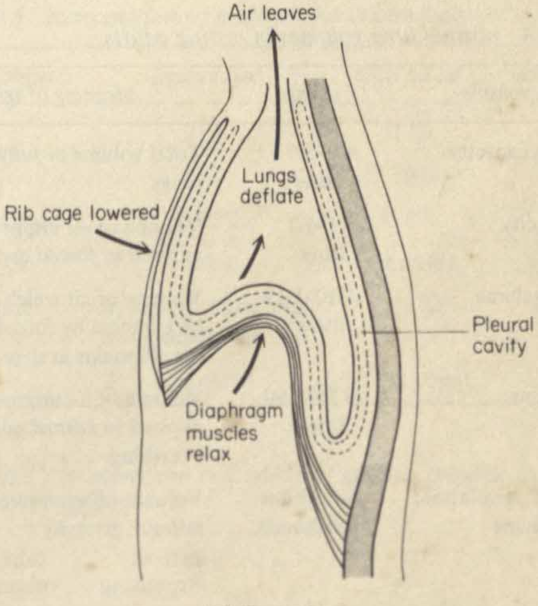
(iv) *carbon dioxide* being *released* from blood plasma.

Table 10.5 shows the varying composition of inspired, expired and alveolar air.

fig 10.9 *ventilation movements in mammals*



(a) Inspiration



(b) Expiration

Table 10.3 *summary of respiratory movements in man*

	Part of respiratory tract	*Inspiration*	*Expiration*
1	Diaphragm	Contracts and flattens downwards	Relaxes and moves upwards to dome shape
2	Intercostal muscles	Muscles contract	Muscles relax
3	Rib cage and sternum	Move upwards and outwards	Move downwards and inwards
4	Thorax volume	Increases	Decreases
5	Air pressure	*Decrease* in pressure inside thorax and lung	*Increase* in pressure inside thorax and lung
6	Air movement	External air pressure drives air *into* lungs at low pressure	Air forced out of lungs by thorax *compression* and *elastic recoil* of lungs
7	Pleural cavity	Pleural *fluid* lubricates pleural membranes	Pleural *fluid* lubricates pleural membranes

Table 10.4 *normal lung volumes in resting adults*

Lung volume	*Range*	*Meaning of term*
Total lung capacity	4.2–5.9 litres	Total volume of *fully inflated* lungs
Vital capacity	3.1–4.7 litres	Volume of air inspired or expired in *forced* breathing
Residual volume	1.10–1.19 litres	Volume of air which *cannot* be expelled by forced breathing. Remains in alveoli
Tidal volume	0.76–0.90 litres	Volume of air inspired and expired in *normal* unforced breathing
Pulmonary ventilation/ minute volume	6–10 litres per minute	Volume of air inspired in one minute, given by rate of breathing × tidal volume

fig. 10.10 *gas exchange in the lung alveolus of mammals*

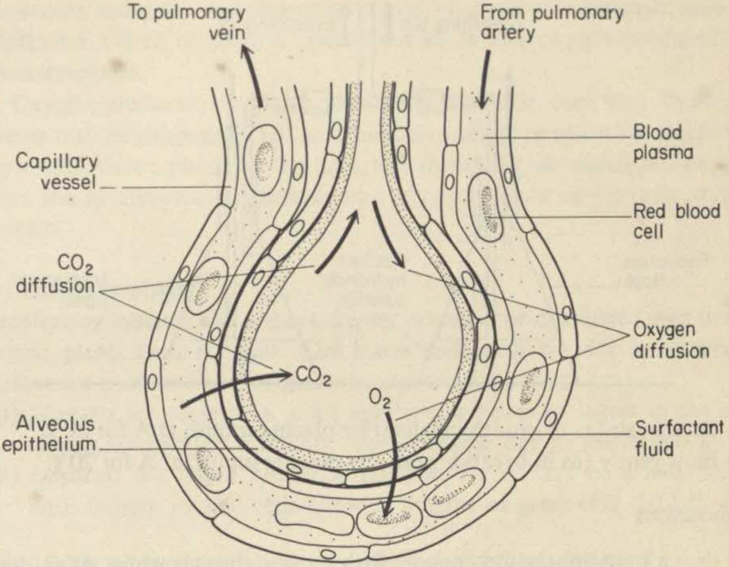


Table 10.5 *composition of inspired and expired air*

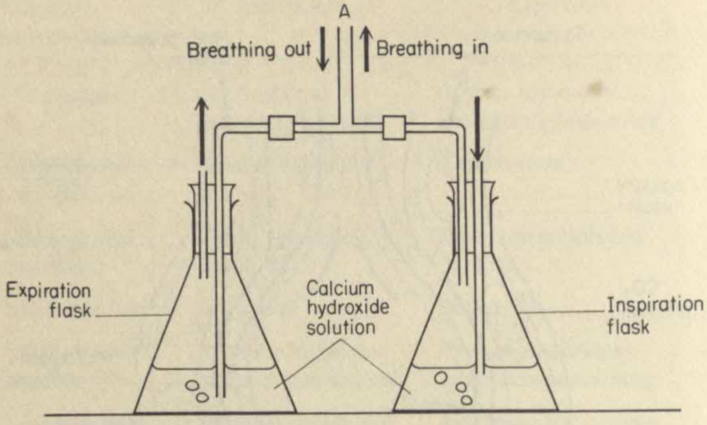
Air component	*Inspired air*	*Expired air*	*Alveolar air*
Oxygen	21%	17%	14%
Nitrogen	79%	79%	80%
Carbon dioxide	0.03%	4%	6%
Water vapour	variable	saturated	saturated
Temperature	prevailing atmospheric temperature	38°C	+40°C
Bacteria	low count	high count	high count

Experiment 10.7 ***to show the formation of carbon dioxide in man*** **(Fig. 10.11)**

Procedure

(i) Prepare the apparatus shown in Fig. 10.11.

fig 10.11 *to demonstrate carbon dioxide presence in exhaled gases in man*



(ii) Suck in air (as in mouth inhaling) by placing mouth at A for 20 s.
(iii) Blow gently (as in breathing out) by placing mouth at A for 20 s.

Observations

Air drawn in on inhalation contains little carbon dioxide whilst air expired contains over 130 times the amount of carbon dioxide present in room air.

(d) Control of respiration in mammals

The normal *breathing rate* for a resting adult is 16 to 20 respiratory cycles per minute, one *respiratory cycle* being composed of inhalation followed by expiration.

The *respiratory centre* of the brain is in the part called the *medulla oblongata* (Section 13.11); this controls the diaphragm and intercostal muscles.

The activity of the respiratory centre is homeostatically controlled *chemically* and by *nervous* activity.

(i) An *increase* in carbon dioxide in the blood stimulates the respiratory centre to produce *faster* and *deeper* ventilation. This occurs in strenuous exercise.
(ii) *Conscious* or voluntary control over breathing is exerted in speaking, singing or playing wind instruments.

Insufficient oxygen or oxygen starvation for more than 2 min causes brain cell damage and final asphyxiation. Hence the need for *speedy* artificial respiration by the 'kiss of life' method.

Excess oxygen or oxygen poisoning causes damage to body cells through excessive oxidation, leading to death. This can occur by breathing pure 100% oxygen under *high* pressure.

10.10 EXTERNAL RESPIRATION IN FLOWERING PLANTS

Flowering and green non-flowering plants, in contrast to animals, have an additional *source* of oxygen apart from *air* in the oxygen produced by *photosynthesis*.

Oxygen produced by photosynthesis will diffuse over very *short distances* into neighbouring cells or from chloroplasts to mitochondria in the *same* cell. Green plants in daylight will therefore use much less oxygen from the *air* compared to animals who rely entirely on air for their oxygen supply.

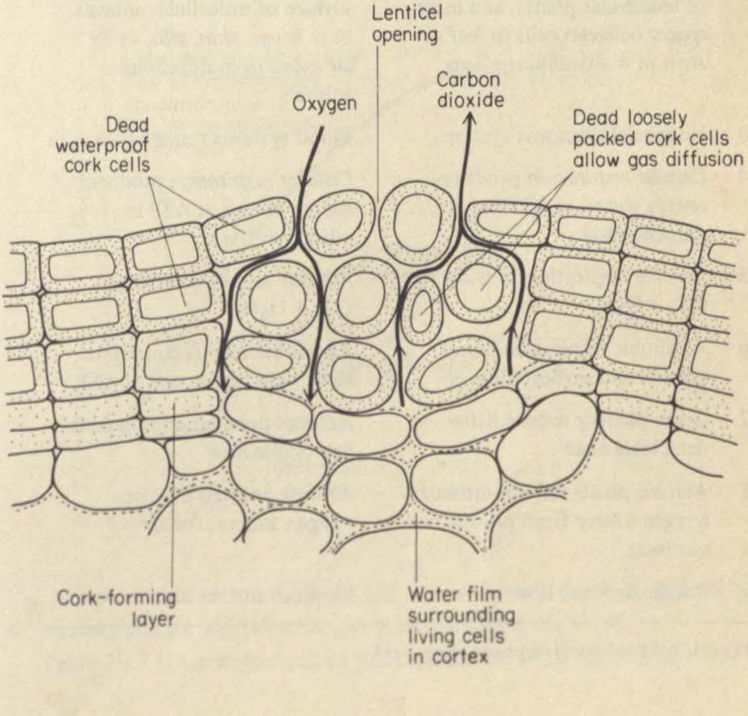
(a) Tissues involved

Respiratory systems and organs are *not* required or developed even in the largest plants such as trees. The leaves and roots provide an extensive surface for entry and exit of gases through the following:

(i) *Stomata* are present in great numbers as pores in leaves in the epidermis layer which is mainly non-permeable due to the *cuticle* layer.

(ii) *Lenticels* are raised breathing pores in the surface of woody stems with loosely packed cells allowing passage of gases (Fig. 10.12). The

fig 10.12 *gas exchange in the stem lenticel of a flowering plant*


Lenticel opening
Oxygen
Carbon dioxide
Dead waterproof cork cells
Dead loosely packed cork cells allow gas diffusion
Cork-forming layer
Water film surrounding living cells in cortex

remaining *bark* of stems has a non-permeable layer of *cork* cells.

(iii) *Root hairs* are without a waterproofing cuticle and the root hair cell walls are *permeable* and permit diffusion. Cultivated soil is *aerated* by digging and ploughing. This *soil air* dissolves in the film of soil water surrounding the soil particles.

(b) Ventilation

Ventilation movements do not occur since plants are *less active* than animals.

(c) Gas exchange

Gaseous exchange occurs after entry of oxygen into the numerous *air spaces* present between cells in the stem leaf and root. Few cells are far

Table 10.6 *comparison of respiration in plants and animals*

	Plant respiration	*Animal respiration*
1	No *external* ventilation movements	*External* ventilation movements in all except small animals, *Amoeba* and *Hydra*
2	*Gaseous exchange* is on cell surface of unicellular plants, and in *air spaces* between cells in *leaf* or *stem* of multicellular plants	*Gaseous exchange* is on cell surface of unicellular animals, or in *lungs, skin, gills*, or by *air tubes* in multicellular animals
3	No special transport system	Blood systems transport oxygen
4	*Cellular respiration* produces energy stored as ATP in mitochondria	*Cellular respiration* produces energy stored as ATP in mitochondria
5	*Aerobic* respiration forms $CO_2 + H_2O$	*Aerobic* respiration forms $CO_2 + H_2O$
6	Anaerobic respiration forms *ethanol* and carbon dioxide	Anaerobic respiration forms *lactic* acid* only, and *no* CO_2
7	Green plants produce little detectable *heat*	Animals produce considerable detectable *heat*
8	Aerobic plants have additional oxygen source from photosynthesis	Aerobic animals have one oxygen source, the air
9	Respiration rate low	Respiration rate high

*Lactic acid = 2-hydroxypropanoic acid.

from an oxygen supply from the air or photosynthetic tissue.

Internal cells have a film of *water* coating their outer surfaces; this is essential to dissolve the respiratory gases prior to *diffusion* across the cell wall. The cell walls are therefore the *respiratory surfaces* of plants.

Table 10.6 compares plant and animal respiration.

(d) Photosynthesis and respiration

External respiration in flowering plants is dependent on *light* intensity.

In *daylight*, photosynthesis *and* respiration occur. Photosynthesis provides oxygen for respiration, whilst respiration provides *carbon dioxide* for photosynthesis.

In *darkness*, respiration only occurs and oxygen uptake from the outside *air* will occur.

In *bright* light, the rate of photosynthesis is *ten* times the rate of respiration, and thus provides an ample oxygen source. With decreasing light, the photosynthesis rate drops until a point is reached when the rate of respiration equals the rate of photosynthesis (Fig. 10.13). This is called the *compensation point*. In very dim or no light at dawn or dusk, the rate of photosynthesis will become *less* than the respiratory rate.

fig 10.13 *graph to show effect of light intensity on photosynthesis*

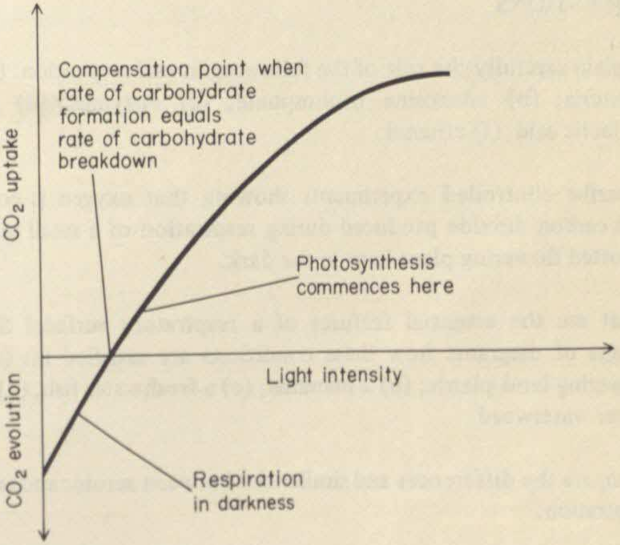


Table 10.7 is a comparison of photosynthesis with respiration.

Table 10.7 *comparison of photosynthesis and respiration*

	Photosynthesis	*Respiration*
1	A process of *anabolism* or *synthesis* of organic materials	A process of *catabolism* or *breaking down* of organic materials
2	Energy *required* from sunlight	Energy *released* and stored as ATP
3	Occurs in cells containing *chloroplasts*	Occurs in all cells containing *mitochondria*
4	Light essential	Occurs at all times in light or dark
5	Oxygen produced	Oxygen needed for *aerobic* respiration
6	Carbon dioxide required	Carbon dioxide produced by plant and animal aerobic respiration, and *plant* anaerobic respiration
7	Typical of all green plants and certain bacteria	Typical of all living organism aerobes and anaerobes

10.11 QUESTIONS

1 Explain carefully the role of the following in *cell* respiration: (a) mitochondria; (b) adenosine triphosphate; (c) enzymes; (d) glucose; (e) lactic acid; (f) ethanol.

2 Describe controlled experiments showing that oxygen is consumed and carbon dioxide produced during respiration of a small insect and a potted flowering plant kept in the dark.

3 What are the essential features of a respiratory surface? Show by means of diagrams how these conditions are satisfied in: (a) green flowering land plants; (b) a mammal; (c) a freshwater fish; (d) a freshwater waterweed.

4 Compare the differences and similarities between aerobic and anaerobic respiration.

5 The following data show the effect of varying light intensity on the mass of carbohydrate made by photosynthesis and that which is used in respiration of a certain green plant maintained at a steady temperature.

Light intensity (klux)	5	10	15	20	25
Units of carbohydrate respired	2.5	2.5	2.5	2.5	2.5
Units of carbohydrate made in photosynthesis	3	7	9	10	10

Draw a graph of these results. Indicate the compensation point and what occurs at this point. What change in an external factor would cause an *increase* in units of carbohydrate respired?

CHAPTER 11

GROWTH

11.1 INTRODUCTION

Growth is a characteristic of living organisms (Section 3.1), and is the increase in size of the organism arising from the *synthesis* of new *structural* material using the *energy* provided by respiration and raw materials from outside the organism.

(a) Features of growth

During growth, the amount of *cytoplasm* generally increases, causing an increase in *length*, *volume*, *area* or *weight* of the organism.

Closely linked with growth is the process of *development* of an organism, when cells *differentiate* into tissues and organs. Plants in their development may form seeds which germinate and show *primary* growth into roots, stems, leaves and flowers. Some plants may show *secondary* growth in trees. Animal development may show profound changes called *metamorphosis* seen in insects and amphibians.

The *overall* growth of multicellular organisms is achieved by increase in the number of body cells as a result of *cell division*; this is accompanied by increase in size of individual cells by *cell growth*.

When the rate of anabolism (see Section 4.10) is *greater* than the rate of catabolism, the organism will show growth. When catabolism *exceeds* anabolism the organism will show a decrease in size and ultimately dies.

Anabolism rate greater than catabolism equals GROWTH

11.2 THE CELL NUCLEUS

A cell *nucleus* (see Sections 16.2 and 16.3) is spherical or egg-shaped and contains one or more *nucleoli* and is the largest cell organelle. A *nuclear* *membrane* surrounds the *nucleoplasm* or nuclear contents, separating it from the *cytoplasm*.

Nucleoplasm is composed of *chromatin* which is chemically a protein, *histone*, and the nucleic acid, DNA or *deoxyribonucleic acid*. When the nucleus is about to divide, the chromatin becomes visible as long threads called *chromosomes*; they are invisible in a *resting* or non-dividing cell.

A cell nucleus is important in controlling *life* in a cell. If an *Amoeba* is cut into three portions, one part with the nucleus and two without, the part with a nucleus grows into a complete cell, whilst the two separate parts without a nucleus die.

Experiment 11.1 *to show the nucleus in root tip cells*

Procedure

(i) Suspend a pink-fleshed onion or shallot bulb with its base just touching the water surface in a container. Leave for 1 week to encourage root formation.
(ii) Cut off 1 cm of the root tip and place in a watchglass containing a solution of 10 parts *acetic orcein* stain and one part normal hydrochloric acid. Warm over a small flame for 5 min.
(iii) Place the specimen on a clean microscope slide, and cut in half with a razor blade. Retain the tip, adding 2–3 drops acetic orcein stain. Break up the tip with a blunt seeker needle.
(iv) Lower a coverslip onto the root tip, cover with a layer of filter paper and gently *squash* the coverslip against the slide. Warm the slide for 10 s.
(v) View the onion root tip squash with low and high power of a light microscope.

Observation

Acetic orcein stain shows up the chromosomes in dividing cells. Nuclei in cells which are *not* dividing are not stained. Most of the dividing cells are in a region close to the root tip. The *number* of chromosomes in a nucleus may be counted and found to be the same for all nuclei in the root tip.

(a) Mitosis

Mitosis is the process by which a nucleus divides into two growing *body* or *somatic* cells. *Two identical* daughter cells form from the division of one parent cell.

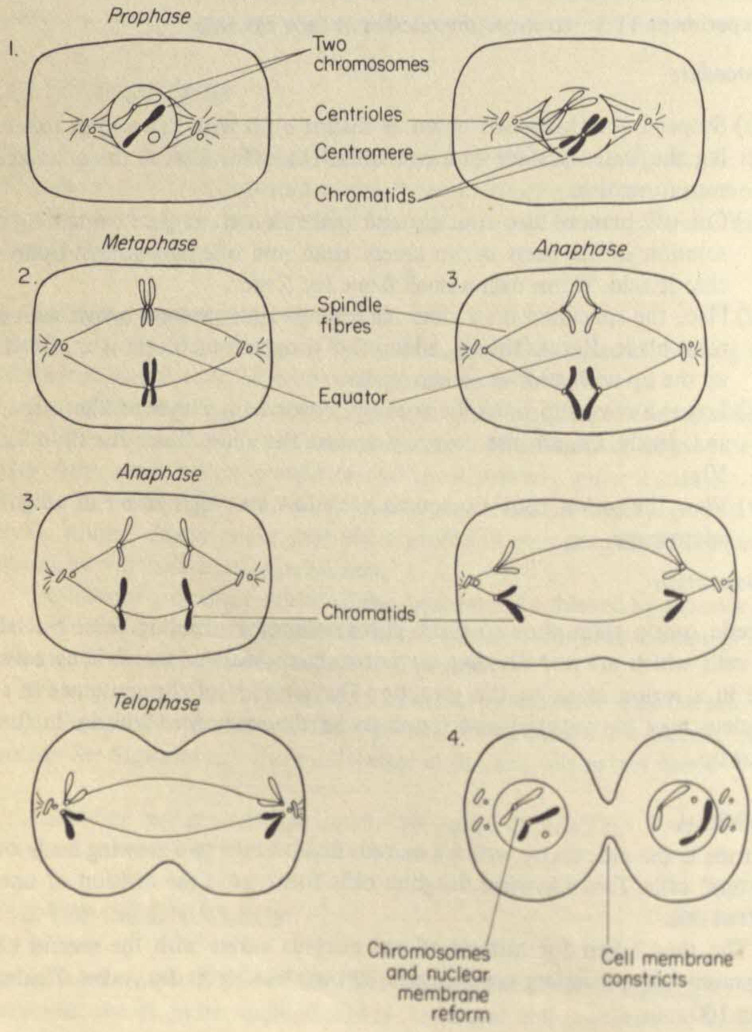
The *time* taken for mitosis of one nucleus varies with the *species* of organism and prevailing *temperature*. *Drosophila*, fruit fly, takes 7 min, man 100 min.

Mitosis is a *continuous* process, but *four* main phases are recognised, each of which merges into the other (Fig. 11.1).

(i) *Prophase*

(1) The *nuclear membrane* disappears.
(2) Chromosomes become visible as two lengthwise halves or *chromatids* which shorten and thicken.

fig 11.1 *mitosis or nuclear division in an animal cell*



(3) Nucleoli disappear.
(4) *Centrioles* in animal cells form poles which are connected to *spindle fibres*. Centrioles are absent in higher plants.

(ii) *Metaphase*

Chromatids arrange themselves on the cell *equator* position or midline.

(iii) *Anaphase*

The *chromatids* are drawn apart and become chromosomes which move towards the opposite poles drawn by the spindle fibres.

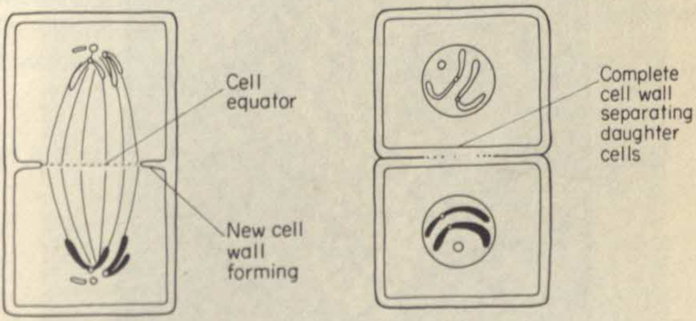
(iv) *Telophase*

(1) Chromosomes reform by an uncoiling process, become thinner, and finally disappear.
(2) Nucleoli reform.
(3) Nuclear membranes reappear.

11.3 CELL DIVISION

While the nucleus is dividing by mitosis, the cell cytoplasm and plant cell wall are also dividing (Fig. 11.2).

fig 11.2 *cell wall formation following mitosis in a plant cell*



Animal cells and *Amoeba* divide by a 'furrowing' of the cytoplasm along the cell equator position.

Plant cells develop a *cell plate* along the cell equator position, which grows inwards to meet the opposite cell plate. Cellulose is then deposited on either side of the cell plate, the original cell having formed two daughter cells.

(a) Cell growth

Following the process of nuclear and cell division, the new daughter cells enter a *period of growth* occupying up to 80% of a cell's lifetime. During this period, *two* important metabolic processes occur, namely *chromosome duplication* and *protein synthesis*.

(i) *Chromosome duplication*

The DNA molecule (Plate 11.1) of a chromosome is known to resemble a double coil or *helix* which can be compared to two intertwining springs or two sides of a twisted ladder. This knowledge is the result of James Watson and Francis Crick's researches. Each strand is composed of *deoxyribose* sugar and *phosphate* units, with thymine, adenine, cytosine and guanine *bases* forming rungs in between (Fig. 11.3).

plate 11.1 *a model of the deoxyribonucleic acid (DNA) molecule showing its twisted form (Sandoz Ltd)*

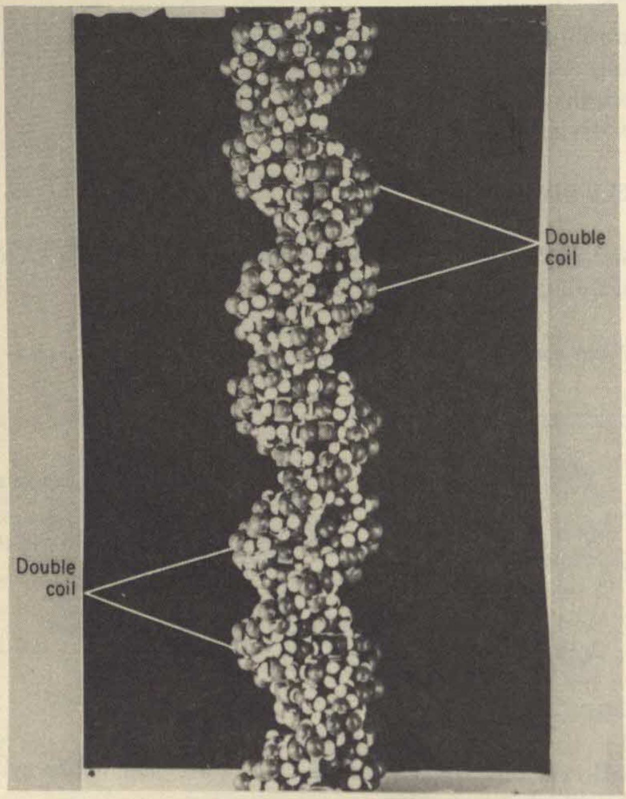
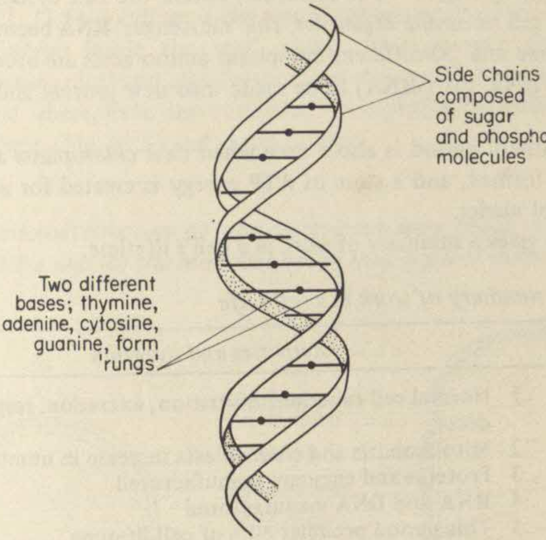


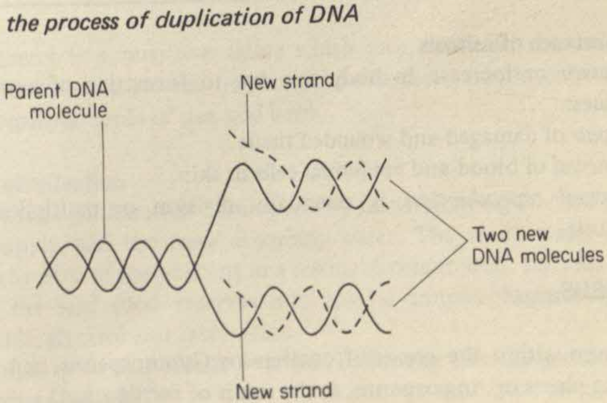
fig 11.3 *the deoxyribonucleic acid (DNA) molecule resembling a twisted ladder, with pairs of different organic bases forming the rungs*


Side chains composed of sugar and phosphate molecules
Two different bases; thymine, adenine, cytosine, guanine, form 'rungs'

Duplication or *doubling* of the DNA molecule takes place by *untwisting* and formation of *single* strands. Single strands pick up deoxyribose sugar, phosphate and base *units* from the nucleus and *reform* double DNA molecule coils (Fig. 11.4).

The overall result is an increase in DNA material in preparation for the next nuclear division by mitosis.

fig 11.4 *the process of duplication of DNA*



(ii) *Protein synthesis*

The *nucleolus* increases in size and 'messenger' ribonucleic acid (or m-RNA), resembling *half* a DNA molecule, enters the cell cytoplasm and travels to the cell *ribosome* organelles. The 'messenger' RNA becomes fixed to the ribosome and 20 different cytoplasm amino acids are brought to it by 'transfer' RNA (or t-RNA) to be made into new *protein* and *enzyme* molecules.

The cell growth period is also a time when new *chloroplasts* and *mitochondria* are formed, and a store of ATP energy is created for use in the next mitosis of nuclei.

Table 11.1 gives a summary of work in a cell's lifetime.

Table 11.1 *summary of work in a cell's life*

Period		*Activities and duration*
Growth	1	Normal cell functions: nutrition, excretion, respiration occur
	2	Mitochondria and chloroplasts increase in numbers
	3	Proteins and enzymes manufactured
	4	RNA and DNA manufactured
	5	This period occupies 80% of cell lifetime
Nucleus division	1	Nucleus divides during mitosis
	2	Contents of nucleus and cytoplasm mix together after nuclear membrane breaks down
	3	This period occupies 15% of cell lifetime
Cytoplasm division	1	The cell's lifetime ends in the formation of two *new* daughter cells
	2	Cells separate by fission in animals or a new cell wall in plants
	3	This period occupies 5% of cell lifetime

(b) Importance of mitosis

(i) *Growth* or increase in body size due to formation of new cells in tissues.

(ii) *Repair* of damaged and wounded tissue.

(iii) *Renewal* of blood and epidermal cells in skin.

(iv) *Asexual reproduction* is essentially division or multiplication by mitosis.

11.4 SEEDS

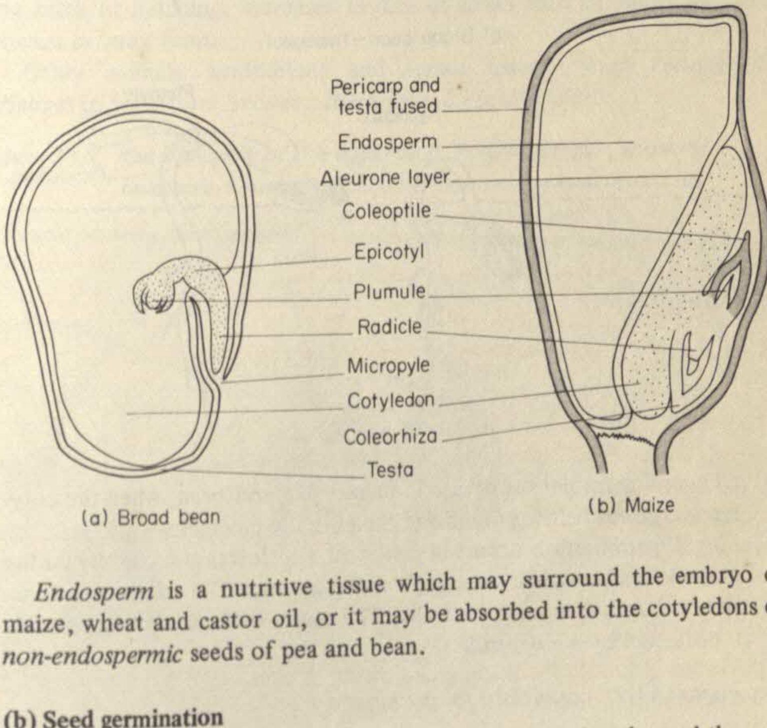
Seeds form within the *cones* of conifers or Gymnosperms, and fruits of flowering plants or Angiosperms, as the result of fertilisation.

(a) Seed structure

Surrounding the seed is a thick seed coat or *testa* providing protection against dehydration, mechanical damage and insect or micro-organism attack (Fig. 11.5). A *hilium* is the scar of the seed stalk.

The *embryo* inside the seed consists of a *plumule* (future shoot), *radicle* (future root) and seed leaves or *cotyledons*. Monocotyledon plants, grasses and wheat, have *one* cotyledon. Dicotyledon plants have *two*, seen in broad bean (Fig. 11.5) and castor oil seed.

fig 11.5 *internal structure of (a) a dicotyledon seed, broad bean,* Vicia faba, *and (b) the monocotyledon fruit grain of maize,* Zea *sp.*



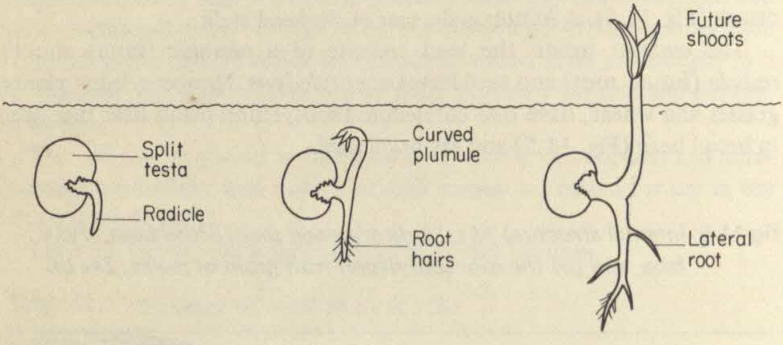
Endosperm is a nutritive tissue which may surround the embryo of maize, wheat and castor oil, or it may be absorbed into the cotyledons of *non-endospermic* seeds of pea and bean.

(b) Seed germination

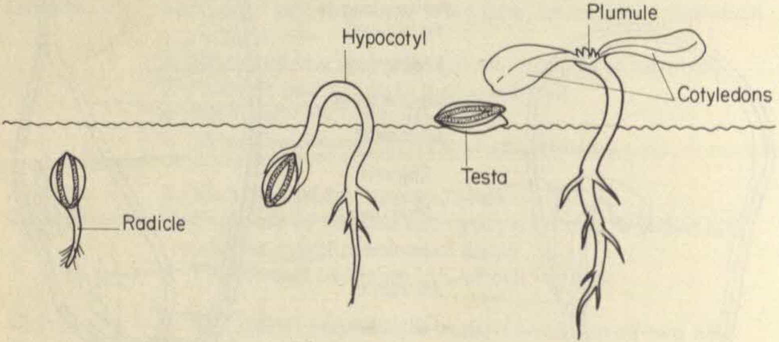
Seed growth or germination commences by *water* entering the seed through the micropyle, and the testa absorbing water. The seed's water content increases by 80% of the content in a resting *dormant* seed. Enzyme activity converts the seed food reserves into soluble simpler forms of glucose, amino acids, glycerol and fatty acids.

The testa splits and radicle emerges. Following this the germination is of two types (Fig. 11.6):

fig 11.6 *germination stages for (a) broad bean,* Vicia faba*, and (b) sunflower,* Helianthus *sp. seeds*



(a) Broad bean – hypogeal



(b) Sunflower – epigeal

(i) *Hypogeal* germination occurs in maize, pea and bean, when the cotyledons *remain* below ground and the plumule emerges.

(ii) *Epigeal* germination occurs in castor oil, sunflower and cress when the plumule *and* cotyledons emerge above ground. The cotyledons function as leaves photosynthetically. The maize and cereal grain plumule is protected by a *coleoptile*.

Experiment 11.2 *conditions for germination*

Procedure

(i) Prepare the *control* by placing soaked cress seeds on wet cotton-wool in an open test tube.

(ii) *Need for water*: place *dry* cress seeds on dry cotton-wool in an open test tube.

(iii) *Need for oxygen*: support soaked cress seeds on wet cotton-wool over a solution of pyrogallic acid and sodium hydroxide in a stopperel tube.

(iv) *Need for warmth*: placed soaked cress seeds on wet cotton-wool in an open test tube in a refrigerator at 4°C.

Maintain all experiments, except (iv), at 25°C for one week.

Observations

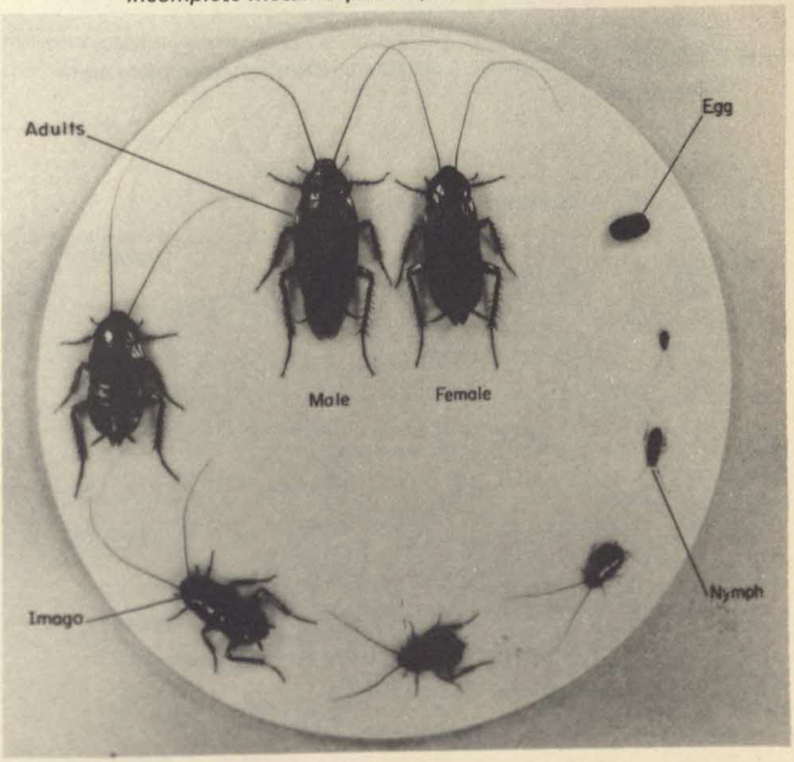
Only the *control* experiment seeds are able to germinate, being provided with water, oxygen and an optimum temperature of 25°C.

11.5 METAMORPHOSIS IN ANIMALS

The fertilised eggs of most animals develop into an *embryo*, which, following birth or hatching, increases in size or *grows* into an adult with little change in body form.

Other animals, amphibians and certain insects, show considerable changes in body form between the fertilised egg and adult.

plate 11.2 *the life-cycle of the cockroach, Periplaneta sp., showing incomplete metamorphosis (Rentokil Laboratories Ltd)*



Metamorphosis is the changes in body form of a *larva* or immature organism into an adult; it is seen in the change from tadpole to frog, and from caterpillar to butterfly.

(a) Insect metamorphosis

Insects can show two different types of metamorphosis in their *life-cycles*.

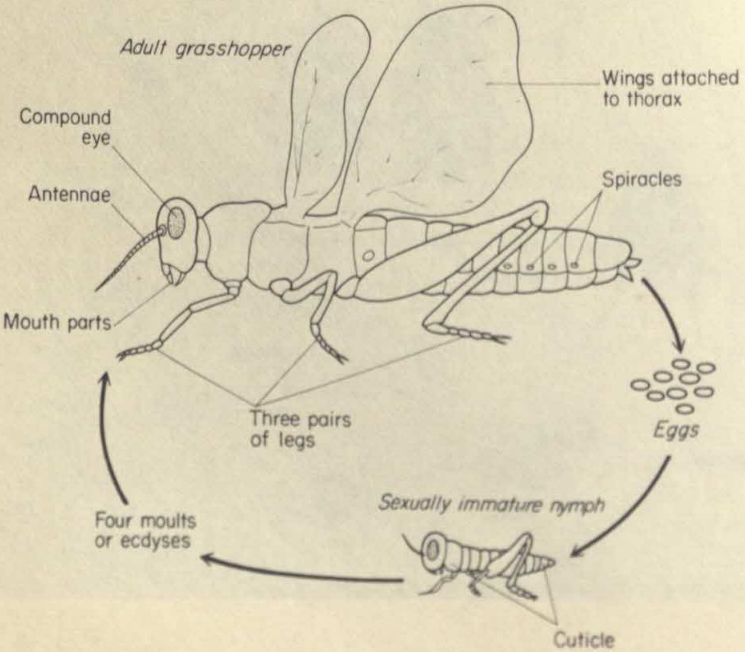
(i) *Incomplete metamorphosis*

This is seen in cockroach (Plate 11.2), locust (Fig. 11.7) and grasshopper life-cycles. The *egg* hatches into a *nymph*, a sexually immature miniature insect, lacking wings. The nymph grows into an adult by passing through several moults or *ecdysis* stages in which it sheds its complete outer skeleton. The stage between successive moults is called an *instar*. It becomes a sexually mature adult after the last moult.

egg ⟶ nymph ⟶ adult

Incomplete metamorphosis

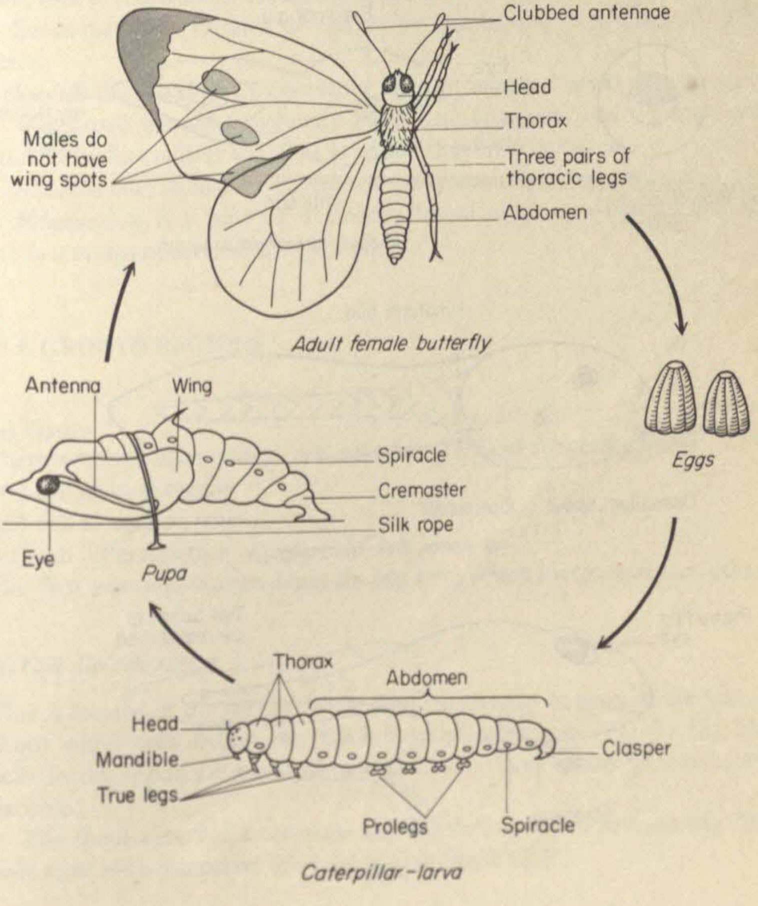
fig 11.7 *life-cycle of the locust,* Locusta *sp., showing incomplete metamorphosis*



(ii) *Complete metamorphosis*

This is seen in the housefly, moth, butterfly (Fig. 11.8) and honey bee life-cycles. The *egg* hatches into a very active *larva* different in form from the adult being a *maggot*, *grub* or *caterpillar*. It feeds differently from the adult and passes through *ecdysis* stages to become an inactive non-feeding *pupa*.

fig 11.8 *life-cycle of the large white butterfly,* Pieris brassicae, *showing complete metamorphosis*



Inside the pupa tissue *reorganisation* occurs involving destruction of certain tissues. The sexually mature adult insect emerges from the pupa.

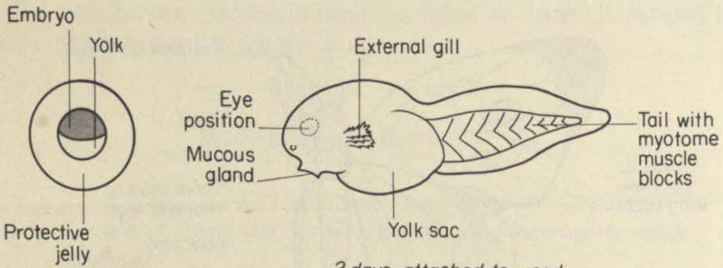
egg → larva → pupa → adult
(maggot or
caterpillar)

Complete metamorphosis

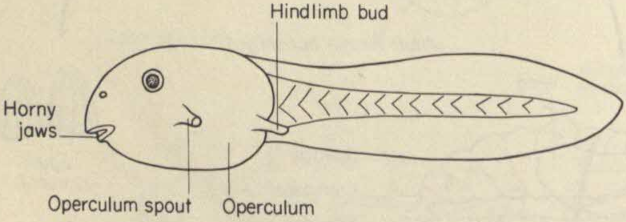
(b) Frog metamorphosis

Stages in the metamorphosis of a frog are shown in Fig. 11.9 and summarised on the next page.

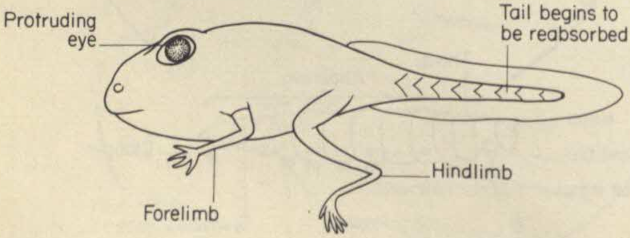
fig 11.9 *outline of life-cycle of the common frog,* Rana temporaria



2 days, attached to weed



6 weeks, free swimming



10 weeks

A free tadpole *larva* emerges from the fertilised egg, attaching itself to a pondweed. It feeds on its *yolk* food reserve and respires by *external* gills.

A mouth develops, allowing the *free*-swimming tadpole to rasp microscopic *algae* off stone surfaces. *Internal* gills protected within an operculum cover replace external gills.

Hindlimbs appear followed by forelimbs, and the gills are replaced by lungs. Feeding is halted whilst the tail is absorbed, and a mouth and tongue develop, allowing a *carnivorous* diet to replace the *herbivorous* earlier diet.

(c) Dormancy

Dormancy is a resting condition with a very low rate of metabolism in which growth ceases. It is seen in seeds, spores, buds, fruits and perennating organs such as bulbs, corms and tubers.

Dormancy is the means to survive adverse conditions of low temperature, lack of moisture in drought and wintery conditions.

Seeds may have variable dormancy periods lasting from one up to 100 years.

Insects show a type of dormancy; *eggs* of human fleas remain dormant in floorboard crevices, butterfly *pupa* hang dormant under ledges, and *adult* houseflies cluster together in winter time in attic spaces.

Amoeba encysts in time of drought and extremes of temperature.

Hibernation is a type of dormancy found in many different animals and is a means of survival over winter.

11.6 GROWTH REGIONS

(a) Plants

There are *three* main *growth* regions (Plate 11.3) in flowering plants:

(i) cell division region;
(ii) cell elongation region;
(iii) cell differentiation region.

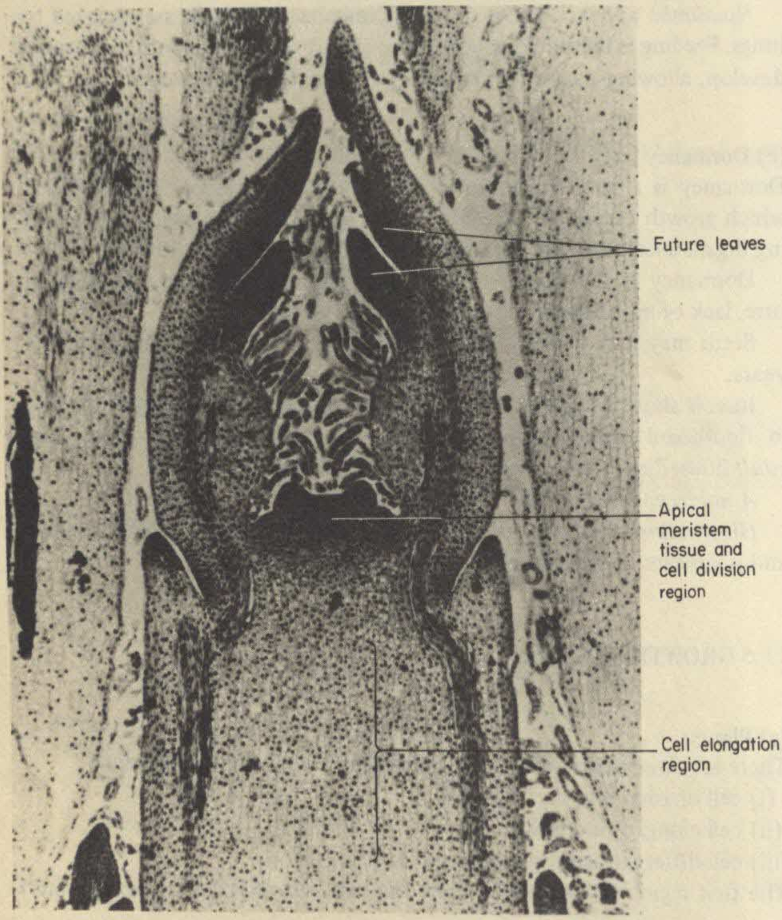
The first region is distinct from the last two, which merge into each other.

(i) *Cell division region*

This is located in the *meristematic* tissue at the tip or *apex* of the root or shoot where cells divide *after* the mitosis of cell nuclei (Fig. 11.10). The cells in this region are small, thin-walled, with large nuclei and without a vacuole.

The shoot apex has a terminal bud and future leaf or *primordium*. The root apex has a protective root *cap* seen in Fig. 11.10.

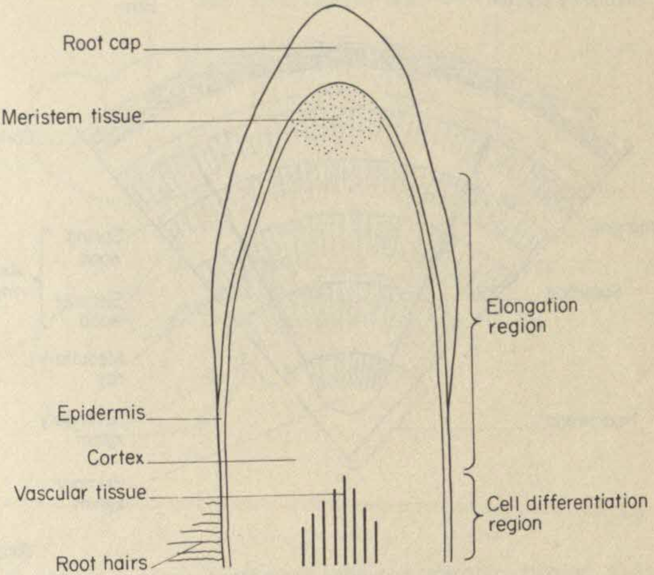
plate 11.3 *a photomicrograph of elder,* Sambucus *sp. stem apex, seen in longitudinal section, showing where cell division and expansion occur (Griffin Biological Laboratories)*



(ii) *Cell elongation region*

This is directly behind the cell division region, and is the part where cells elongate or expand (Fig. 11.10). Elongation occurs by the formation of a *vacuole* in the cytoplasm. Water is absorbed by osmosis causing the cytoplasm to increase in volume, resulting in the thin cell walls stretching.

fig 11.10 *longitudinal section through a root showing cell division and elongation regions*



(iii) *Cell differentiation region*

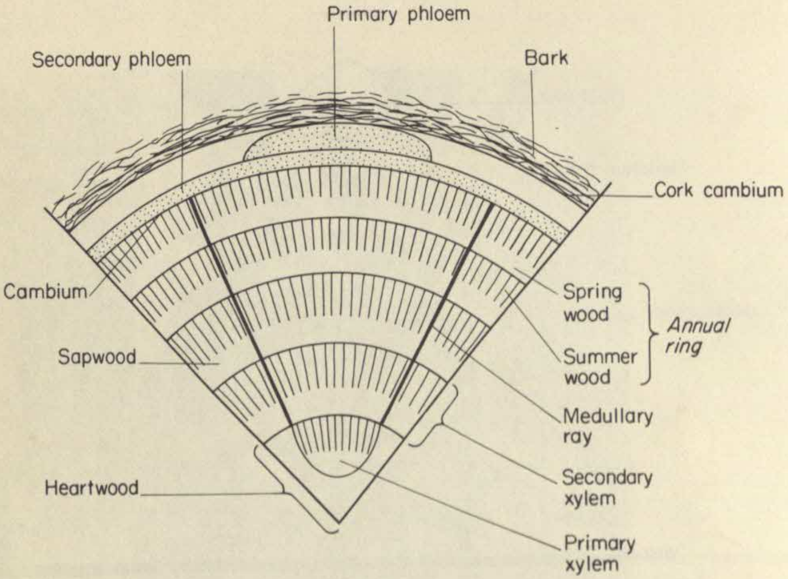
This is where the elongated cells develop the characteristic structure of the different *tissues* of the cortex, xylem, phloem and cambium. This results in the *primary* unthickened structure of stems and roots described in Section 3.10.

The result of primary growth is an increase in *length*.

Secondary growth (Fig. 11.11) occurs in *perennials*, shrubs and trees, and some *biennials*. The main growing region is the continuous *ring of cambium*, a meristem producing rings of secondary xylem *inwardly* and secondary phloem *outwardly*. The xylem becomes *wood*, whilst the soft phloem becomes *bast* beneath the outer *bark*.

The overall result of secondary growth is an increase in *girth* or diameter. Splitting of the outer surface tissue is prevented by a *cork* cambium producing waterproofing cork-filled cells in the bark (see Fig. 10.12).

fig 11.11 *transverse section of a portion of a woody stem showing secondary thickening*



Experiment 11.3 *to show the elongation region in a broad bean radicle* (Fig. 11.12)

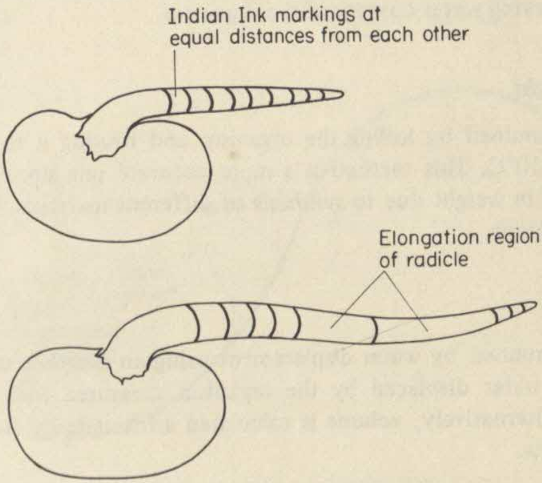
Procedure

(i) Germinate soaked bean seeds sandwiched between several thicknesses of rolled up paper tissues kept continually moist. This method produces bean seedlings with *straight* radicles after 8 days.
(ii) Prepare a *marker* by wrapping cotton around a slotted wooden support with 3 mm between each thread turn.
(iii) Dry the straight bean radicle. Damp the *marker* with Indian ink and stamp it gently on the radicle producing *equal* spaced marks along its length. Allow to dry.
(iv) Return the marked seedlings sandwiched in the layers of the damp paper tissue roll.

Observations

After several days examine the radicle tip carefully. The point where greatest movement between ink marks is to be seen is the *elongation region*.

fig 11.12 *to show the elongation region in a broad bean,* Vicia faba, *seed radicle*


Indian Ink markings at equal distances from each other
Elongation region of radicle

(b) Animals

The fertilised egg nucleus undergoes repeated mitotic division to produce a mass of *undifferentiated* cells called a *blastula*.

Differentiation follows, by the cells moving into three main groups:

(i) *endoderm* – future gut;
(ii) *mesoderm* – future muscle and blood;
(iii) *ectoderm* – future skin and nervous system.

This process of differentiation is called *gastrulation*.

Insects show *intermittent* growth in shedding the chitin exoskeleton by ecdysis.

Mammals, including man, show a type of growth when different body parts grow at different rates from the overall body growth rate. The human brain and eye grow more slowly than the arms and legs.

11.7 GROWTH MEASUREMENT

Growth can be defined as the permanent increase in biomass, cell numbers or body size as a result of anabolic synthesis, cell division and cell expansion.

Growth of an *individual* organism can be measured by the following methods.

(i) *Total fresh weight*

This is measured when the organism is weighed at regular intervals, a method used for most large animals including man. The method is influenced by varying water content of the organism.

(ii) *Dry weight*

This is determined by killing the organism and heating it to a constant weight at 110°C. This method is a more accurate one since it indicates the increase in weight due to *synthesis* of different materials, irrespective of water content.

(iii) *Volume*

This is determined by water displacement using an *overflow* can and the volume of water displaced by the organism measured with measuring cylinders. Alternatively, volume is calculated arithmetically from surface measurements.

(iv) *Photographs*

Photographic methods of *time-lapse* photography can be used to record graphically growth and movements in plants.

(a) Growth curves

The results of growth measurement in *individual* organisms can be displayed as either *ordinary growth* curves or *rate-of-growth* curves.

(i) *Ordinary growth curves*

These are constructed in a graph using *measurements* of a particular character, length or dry weight, plotted against *time* in days (Fig. 11.13).

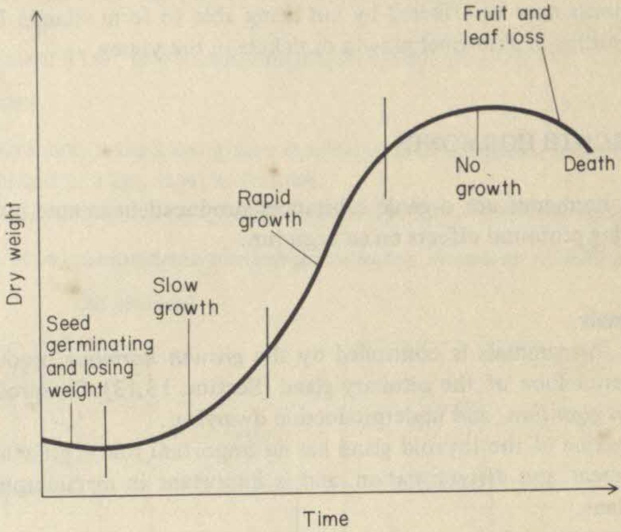
(ii) *Rate-of-growth curves*

These are graphs constructed using growth *increments* or differences in a particular character. For example, if growth is recorded in length as follows: 12, 14, 18, 26, 36, 52, 64 and 75 cm, the increments or changes will be: 2, 4, 8, 10, 16, 12, 11 cm.

The first set of results is used to construct *ordinary* growth curves and the second set, using increments, is used to construct *growth-rate* curves.

Growth-*rate* curves have a typical *bell* shape.

fig 11.13 *graphical illustration of growth in an annual flowering plant*



11.8 GROWTH FACTORS

(a) Genes

Genetic or *inherited* factors are controlled by *genes* in the chromosome. Plants and animals inherit the *trait* to grow tall or remain dwarfed as in garden peas.

(b) Nutrition

Nutrition in a *balanced* diet is essential for healthy growth of animals. Deficiencies of certain minerals, proteins and vitamins A and D result in stunted growth. Similar deficiencies of minerals affect plant growth.

(c) Chemicals and drugs

Carcinogenic chemicals, e.g. tobacco tars, cause cells to divide haphazardly to produce *neoplasms* or cancer tumours in mammals. *Antimitotic* drugs slow down mitosis of cell nuclei and are used in treatment of cancer *neoplasms*.

Thalidomide caused malformation of limbs in human embryos, hindering their normal growth due to the drug's *teratogenic* or malforming effect.

(d) Light

Plants in shade or darkness grow tall, and overcrowded plants tend to seek better positions facing the light.

Mammals may be affected by not being able to form vitamin D in the skin, resulting in abnormal growth or rickets in the young.

11.9 GROWTH HORMONES

Growth hormones are organic substances produced in minute quantities and having profound effects on an organism.

(a) Animals

Growth in mammals is controlled by the *growth hormone* produced in the anterior lobe of the pituitary gland (Section 13.13). Overproduction produces *gigantism*, and underproduction *dwarfism*.

Thyroxine of the thyroid gland has an important role in growth, tissue development and differentiation, and is important in metamorphosis of amphibians.

Metamorphosis in insects is controlled by a hormone, *ecdysone*, secreted by glands in the thorax, triggered by a hormone from the insect brain.

(b) Plants

Plant hormones are of three main kinds: *auxins*, *gibberellins* and *cytokinins*.

Auxins include different compounds, the main one being *indole acetic acid* (IAA). They are produced in the tip or apex of stem and root in the apical meristems.

A stem or root apex can be cut off the root or shoot, then placed on an *agar-agar* block when auxins will diffuse and accumulate in the block.

Auxins can be manufactured on a large scale and are used to 'root' cuttings and kill broad-leaved weeds, daisy and dandelion.

11.10 TROPISMS – GROWTH MOVEMENTS

Tropisms are *growth movements* by part of a plant *towards* or *away* from a particular stimulus.

Growth towards a stimulus is *positive*, growth away from the stimulus is *negative*.

The two main external stimuli in plants are those of *light* and the force of *gravity*.

(a) Phototropism

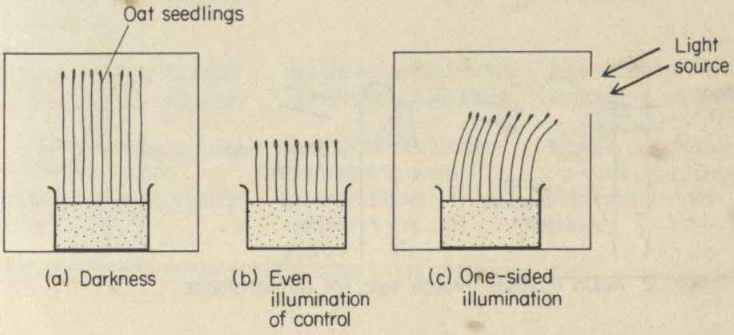
This is the response to light. Shoots are positively phototropic in growing towards light. The majority of roots are not affected.

Experiment 11.4 *to demonstrate phototropism* (Fig. 11.14)

Procedure

(i) Germinate soaked oat grains in small pots of compost. When grown to a height of 1 cm, treat as follows:
  (a) Cover one set completely with a large box, excluding all light.

fig 11.14 *to demonstrate phototropism in oat,* Avena *sp., seedlings*



  (b) Cover another with a box with a side opening, allowing one-sided illumination.
  (c) Leave the *control* set exposed.

(ii) Set apart and maintain at 25°C for a few days.

Observations

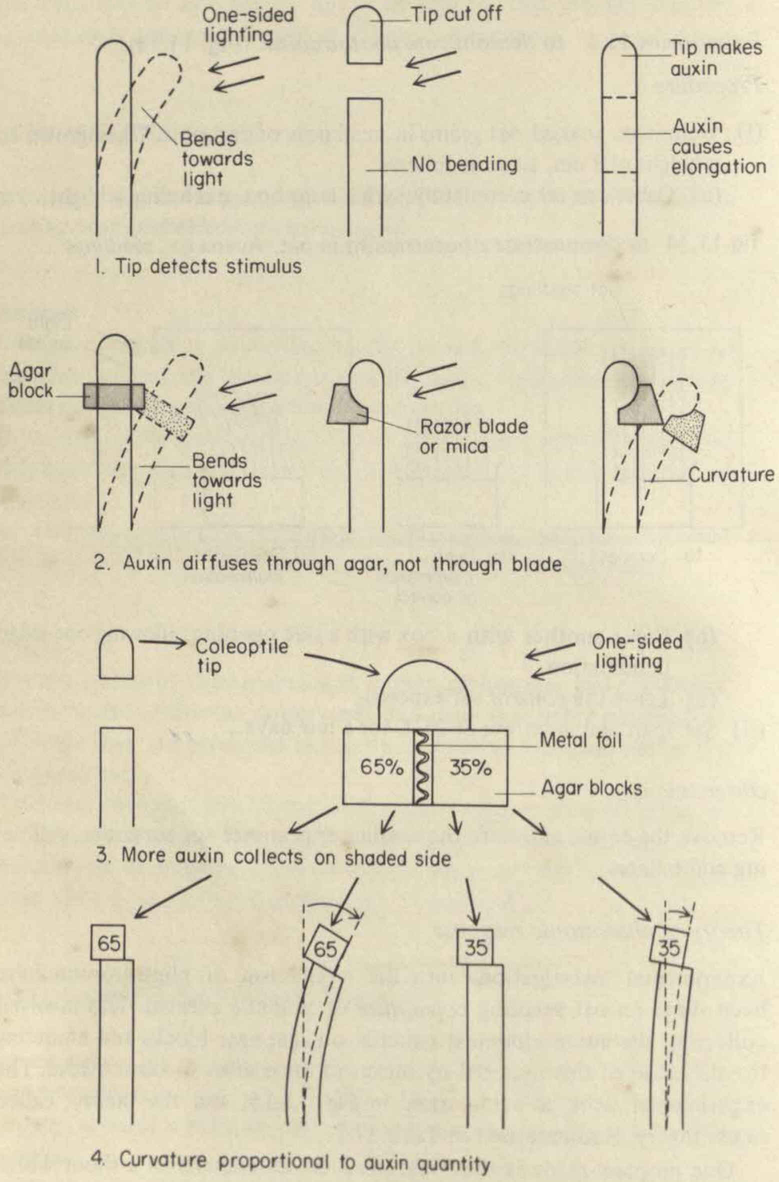
Remove the covers and note the seedling appearance for curvature, yellowing and tallness.

Theory of phototropic response

Experimental investigations into the mechanism of phototropism have been done on oat seedling *coleoptiles* or plumule sheaths. This involved collecting the auxin chemical material on agar-agar blocks and hindering the diffusion of this material by means of *mica* discs or razor blades. The experimental work is summarised in Fig. 11.15, and the theory, called *auxin* theory, is summarised in Table 11.2.

One proposal made is that light produces an *enzyme* in a shoot which *destroys* auxin, preventing cell elongation on the light side, but not on the dark side.

fig 11.15 *summary of experimental work and theory of phototropism*



1. Tip detects stimulus

2. Auxin diffuses through agar, not through blade

3. More auxin collects on shaded side

4. Curvature proportional to auxin quantity

Table 11.2 *auxin theory of phototropic response*

	Even illumination	*Total darkness*	*Uneven illumination*
1	Seedling shoot evenly illuminated on *all* sides	Seedling shoot grown in dark	Seedling shoot receives light on *one side*
2	Auxin distributed *evenly*	Auxin distributed *evenly*	Auxin distributed *unevenly*
3	Auxin produced in *smaller* concentration on *all* sides, or light destroys *same* amount of auxin	Auxin concentration same on *all* sides. *No* light to destroy auxin	Auxin concentration *greater* on *dark* side, or auxin is *destroyed* on light side
4	Auxin causes 'normal' *elongation* on *all* sides	Auxin causes *increased* elongation on *all* sides	Auxin causes *increased* elongation on dark side
5	Results in 'normal' upward growth. Shoot straight, sturdy and green	Results in *etiolation*, increased upward growth. Shoot spindly, weak and yellow	Results in *bending* towards light. Shoot bent, sturdy and green

(b) Geotropism

This is the response to gravity. Roots are usually positively *geotropic* and shoots negatively geotropic.

Experiment 11.5 *to demonstrate geotropism* (Fig. 11.16)

Procedure

(i) Prepare broad bean seedlings with straight radicles as in Experiment 11.3.

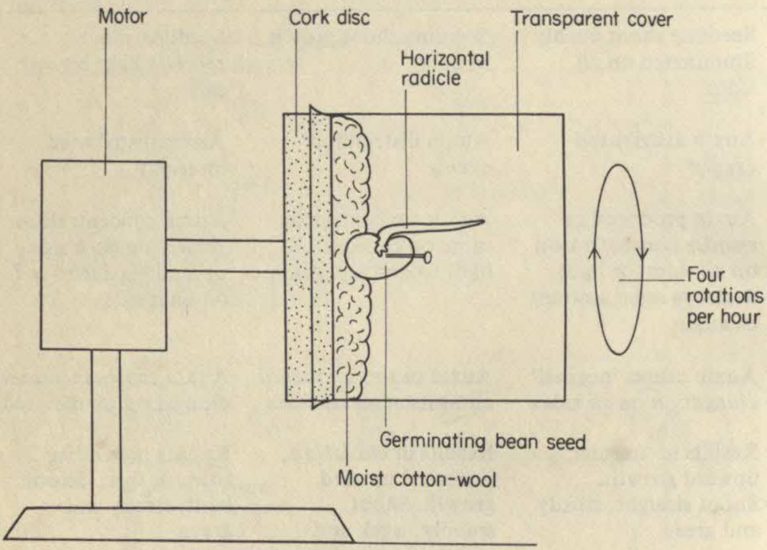
(ii) Obtain a *klinostat*, a mechanically driven, cork-covered disc, rotating four times an hour.

(iii) Pin the seedlings with their radicles projecting horizontally from the cork disc. Cover with transparent covers lined with moist blotting paper to maintain humidity. Allow the klinostat to rotate for 2 days.

(iv) Stop the klinostat rotating and note the shape and appearance of the bean radicles.

(v) Renew the moisture in the blotting paper lining of the cover. Leave the apparatus static for a further 2 days.

fig 11.16 *experimental work with a klinostat*



Observations

The *rotating* disc allows gravity to act equally on *all* sides of the growing bean radicle. The static klinostat allows gravity to act on *one* side of the bean radicle.

The *rotated* seedlings have straight radicles, whilst the *static* radicles show a curvature down towards gravity.

Theory of geotropic response

Roots without a root tip or apex do not respond to gravity.

Roots are *more* sensitive to auxin; very small amounts stimulate root cell elongation, whilst *larger* amounts retard elongation. This is the opposite effect to the action in shoots.

Auxin collects on the lower side in greater concentrations than on the upper side of the root. Consequently, the upper side cells elongate, causing curvature towards gravity.

Table 11.3 compares geotropic response in roots and shoots.

Table 11.3 *auxin theory of geotropic response of main root and shoot*

	Shoot	*Main root*
1	Seedling grown in *horizontal* position in total dark	Seedling grown in *horizontal* position in total dark
2	The horizontal shoot bends upwards	The horizontal radicle bends downwards
3	The shoot is *negatively geotropic* in its response to gravity	The radicle is *positively geotropic* in its response to gravity
4	The *lower* side of shoot has *greater* auxin concentration than upper side	The *lower* side of radicle has a *greater* auxin concentration than upper side
5	Auxin in greater concentration *increases* elongation of cells on *lower* side	Auxin although in greater concentration *prevents* or *decreases* elongation of cells on lower side
6	Results in unequal growth *upwards*, curvature	Results in equal growth *downwards*, curvature
7	Auxin concentration is *highest* in shoot tips	Auxin concentration is *lowest* in root tips

Table 11.4 provides a general comparison of growth in plants and animals.

11.11 QUESTIONS

1 Give an illustrated account of how a cell divides in the stem or root apex regions.

2 Describe the germination of a bean seed and state what *three* conditions are necessary for the seed to germinate. Describe an experiment to find the region of elongation of the bean seed radicle. What happens to the cells in this region?

3 Compare the differences in the ways a *named* plant, a *named* animal and a crystal of a chemical compound grow. Indicate how the age of a fish and a tree can be determined.

Table 11.4 *comparison of growth in plants and animals*

	Plant growth	*Animal growth*
1	Cell division at tips of roots and stems – *apical meristems* and cambium. Mature xylem, phloem and parenchyma cells do not divide	Cell division *throughout* body, mainly in skin, epithelia and bone marrow. Mature blood, bone, muscle and nerve cells do *not* divide
2	Growth results in increase in length and girth	Similar
3	Growth leads to a branching shape	Growth produces a compact shape
4	Has a high surface area/volume ratio	Low surface area/volume ratio compared to plants
5	Growth is mainly continuous except in dormancy, and leaf fall in perennials.	Growth is limited in most animals. Is intermittent in insects – moulting or metamorphosis
6	Growth is uniform in all parts	In man, different parts of body grow at different rates
7	Growth limited in unicellular plants by surface area/volume ratio	Similar

4 What is meant by the term 'metamorphosis'? Describe the metamorphosis in an organism which shows ecdysis.

5 The following data show changes in body length and head circumference measurements during the growth of a child. Construct an ordinary growth curve graph to compare the changes in head and body measurements. What can be said concerning growth in a young child?

Age	Birth	6 months	1 yr	1½ yr	2 yr	2½ yr	3 yr
Body length (cm)	50	65	75	80	90	95	100
Head circumference (cm)	35	40	45	50	50	50	50

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CHAPTER 12

HOMEOSTASIS

12.1 PRINCIPLES OF HOMEOSTASIS

Homeostasis is the maintenance of a *steady state* in living organisms by control of the *internal environment*, despite changes in the external environment. Claude Bernard (1813-1878), a physiologist, was the first to recognise the importance of the steady internal environment.

The *internal environment* is the *tissue fluid* which bathes the cells of multicellular higher animals (see Fig. 9.11). Tissue fluid has *chemical* and *physical* components which must be kept within a narrow quantitative range called 'norms' or 'set points', in order to maintain the steady state. Any changes from the 'norm' will be automatically corrected by *homeostatic control mechanisms.*

Table 12.1 summarises the norm values of the main components of tissue fluid or the internal environment.

Table 12.1 *summary of norm values for tissue fluid components*

Component	*Norm range*	*Mean or average*
Water	97-99%	98%
Glucose	0.08-0.13%	0.1%
Amino acids	0.03-0.05%	0.04%
Lipids	0.2 -0.5%	0.30%
Carbamide (urea)	0.02-0.04%	0.03%
Sodium ions	0.3 -0.36%	0.30%
Acidity or alkalinity (pH)	7.34-7.43	7.4
Temperature	37-39°C	38°C

Note: Blood composition will *vary* in different body tissues; gut may have more water, kidneys more urea (carbamide) and the liver a higher temperature than other body tissues.

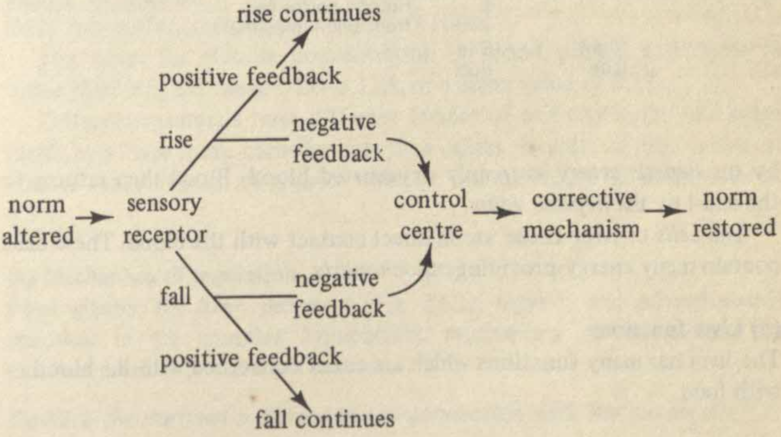
(a) Homeostatic control processes

Homeostatic controls in living organisms are automatic and self-adjusting and function in a similar manner to controls in *machines*, for example the *thermostat* in water baths and aquaria. The study of control mechanisms in machines and living organisms is called *cybernetics*.

Any change in the norm of a tissue fluid component is detected by *sensory receptors* which are part of the nervous system (Section 13.3). These send information by *feedback* to a *central control* system, usually in the brain.

The central control causes *corrective mechanisms* by means of *nerves* or *hormones* to operate, which either increase or decrease the particular feature and bring it back to the norm; this is *negative* feedback.

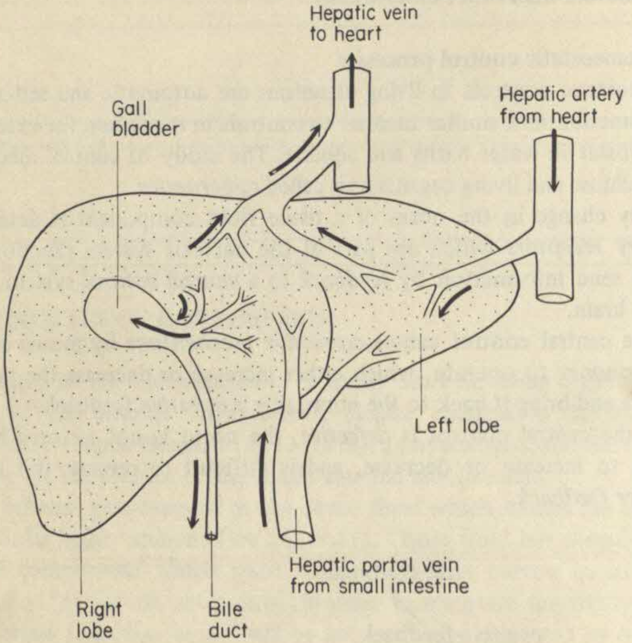
If the central control is *defective*, the norm is not restored but continues to increase or decrease, and is difficult to reverse; this is called *positive feedback*.



12.2 THE LIVER

The human liver weighs about 1.5 kg, and is located beneath the diaphragm, above the stomach in the abdominal cavity.

Two blood vessels supply it with blood at the rate of 1.5 litres per minute (Fig. 12.1). The *hepatic portal vein* provides 80% of the blood and is rich in food nutrients from the small intestine. The remaining 20% is provided fig 12.1 *the mammal liver blood supply*



by the ***hepatic artery*** as mainly oxygenated blood. Blood then returns to the heart by the ***hepatic veins***.

The ***cells*** of liver tissue are in direct contact with the blood. These cells contain many energy-providing ***mitochondria***.

(a) Liver functions

The liver has many functions which are either concerned with the blood or with food.

(i) *Blood functions*

(i) *Red blood cell* formation in embryo and destruction in adult.
(ii) *Blood plasma protein*, fibrinogen, prothrombin and albumen formation.
(iii) *Storage* of blood up to 1.5 litres in the liver veins.
(iv) *Heat production* amounting to 12% of body's heat supply.
(v) *Detoxification*, conversion of harmful poisons and drugs into harmless substances.

(ii) *Food functions*

(i) Homeostatic regulation of ***sugar glucose***, by adding or removing it from blood, glucose being converted to insoluble ***glycogen***.

(ii) Homeostatic regulation of ***lipids***.

(iii) Homeostatic regulation of ***proteins***. Amino acids not required for enzyme making, cell construction or repair ***cannot*** be stored. Surplus amino acids are converted by ***deamination*** into ***ammonia*** and carbohydrate, the carbohydrate being either used to provide cell energy or stored as glycogen. *Ammonia* is formed in most invertebrates and bony fish, whilst birds, reptiles, insects and molluscs convert amino acids into insoluble ***uric acid***. Mammals and adult amphibia convert ammonia into less toxic ***urea*** (carbamide).

(iv) *Vitamins* A, D and B_{12} are stored in the liver, and ***iron*** is also stored.

(v) *Bile* juice formation.

12.3 BLOOD SUGAR CONTROL

Soluble blood sugar ***glucose*** is the source of ***energy*** for ***all*** living cells. The ***brain*** and ***nerve*** cells have ***no*** energy reserves and must have a ***continuous*** supply of glucose; if deprived of glucose, the cells are harmed and the body may suffer convulsions and enter a coma.

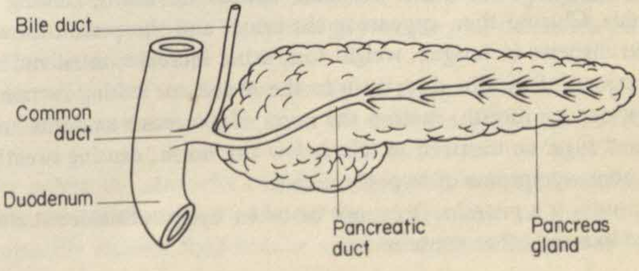
The norm for glucose concentration in blood plasma and hence in ***tissue fluid*** is in the range 0.06–0.13%, or a mean value of 0.1%.

Different mammals have different ***intakes*** of carbohydrates, and some meals may have more carbohydrate than others. In spite of this, the blood plasma concentration of glucose must be maintained at the norm value of 0.1%.

(a) Mechanism of regulation

Four glands, the ***liver, pancreas*** (Fig. 12.2), ***thyroid*** and ***adrenal*** glands function in the complex homeostatic mechanism of maintaining the constant level of blood sugar glucose.

fig 12.2 *the mammal pancreas and its connection with the duodenum*



(i) *Glucose addition to blood*

Addition of glucose occurs when the concentration falls below the norm of 0.1% in *hypoglycaemia.*

Sensory centres in the brain detect a low glucose concentration and by *negative feedback* set off the following *corrective mechanisms* to restore the norm:

(i) *Glycogen* reserves in the liver are changed into glucose by the hormones *adrenaline* (adrenal gland) and *glucagon* (pancreas). In this way sufficient glucose can be provided from the liver reserve for maintaining the norm for 12 h.

(ii) After all the liver glycogen reserves are consumed and there is no further intake of carbohydrate food, the non-carbohydrate *food reserves* are used. Lipids from the fat deposits are changed into glucose by adrenaline. This occurs in *slimming*. Proteins of muscles are converted into glucose by another adrenal gland hormone; this causes muscle wastage seen in extreme *starvation.*

(ii) *Glucose removal from blood*

An *increasing* concentration of blood sugar glucose above the norm causes *hyperglycaemia.* Sensory centres in the *pancreas* and brain by negative feedback set off the following corrective mechanisms:

(i) *Insulin* is a hormone produced by the islets of Langerhans in the pancreas. Insulin was first discovered by Frederick Banting (1891–1941), a physiologist. It causes the liver to remove surplus glucose and change it into insoluble glycogen. Up to 100 g of glycogen can be stored in the human liver.

(ii) Glucose which cannot be stored in the liver accumulates in the skeletal muscles as glycogen; up to 400 g is stored in human muscle.

(iii) Further surplus glucose is then stored as lipids in the fat depots causing *obesity*.

(b) Sugar diabetes

When the pancreas is *defective* it is unable to produce insulin. The blood sugar glucose concentration *increases* above the norm, causing hyperglycaemia. Glucose then appears in the urine, and the person shows signs of sugar diabetes in fatigue, weight loss, urine increase, thirst and hunger.

Injections of insulin directly into the blood, or taking certain tablet preparations by mouth, restore the norm; if excessive amounts are used, the blood sugar concentration falls *below* the norm, causing sweating and finally coma symptoms of hypoglycaemia.

As insulin is a *protein*, it cannot be taken by mouth since it would be digested like any other protein.

12.4 EXCRETION

Excretion is the process of removing the waste products of *metabolism* from the body. The main excretory products are:

(i) *respiratory* waste products, carbon dioxide and water (this water is called *metabolic water*), and

(ii) *nitrogenous waste*, the main excretory product of animals unable to use and store amino acids, and includes ammonia, uric acid and carbamide (urea), the product of deamination in the liver.

Certain plants produce nitrogen-containing materials called *alkaloids*, such as nicotine in tobacco leaf, and quinine in Cinchona bark. Plants are able to use nitrogen in the further synthesis of amino acids and consequently do not produce nitrogenous excretory products and have no specialised *excretory organs* such as the kidneys in mammals.

12.5 OSMOREGULATION

The concentration of *water* in the *tissue fluid* of animals is maintained within the range 97–99%, or a mean of 98%. If the norm is exceeded, water collects in the tissues causing *oedema*; if it falls below the norm, the tissues suffer *dehydration.*

Movement of water into and out of living cells is by *osmosis.*

Osmoregulation is the control of the osmotic pressure or *amount* of water *and* dissolved substances in the organism.

The control of water and mineral ions, sodium, potassium, chloride and sulphate, in animals is combined in the *same* excretory organ.

Excretion and osmoregulation are *both* processes concerned with *blood plasma* and *tissue fluid* homeostasis. They are closely linked and almost inseparable homeostatic mechanisms.

12.6 EXCRETION AND OSMOREGULATION IN ANIMALS

(a) *Amoeba*

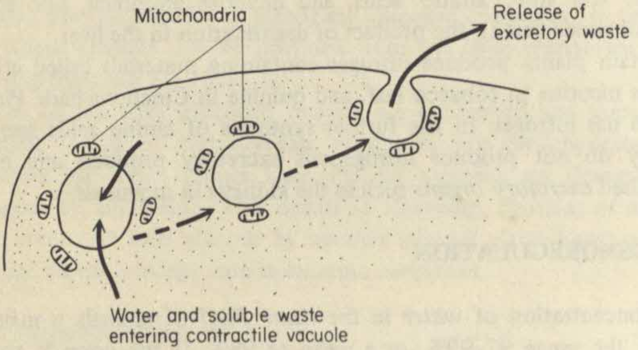
Freshwater unicellular protozoa have a *contractile vacuole.* This collects soluble excretory waste, possibly ammonia, from the cytoplasm by diffusion and active transport. Many energy-providing mitochondria surround the contractile vacuole.

Soluble substances are also able to *diffuse* along concentration gradients through the plasma membrane from the cytoplasm into the surrounding water.

Water enters the *Amoeba* cell from the pond water by *osmosis,* thus increasing the concentration of water above the norm for the cytoplasm. The contractile vacuole functions as an *osmoregulator* and withdraws the excess water from the cytoplasm and restores the norm for water concentration.

The contractile vacuole moves to the cell surface and discharges both water *and* excretory products into the external environment (Fig. 12.3).

fig 12.3 *the process of excretion in* Amoeba *sp.*


Mitochondria
Release of excretory waste
Water and soluble waste entering contractile vacuole

(b) Freshwater fish

Bony fish, such as trout, take in water by *osmosis* through the gill semipermeable membrane – they do not drink water. Mineral ions are taken into the gills by active transport from the surrounding water.

The nitrogenous waste is mainly *ammonia* which can diffuse out of the body by way of the gills, or pass out through the kidney in copious *dilute* urine.

Freshwater fish therefore *eliminate* surplus water and *take up* mineral ions.

(c) Seawater fish

A bony fish, such as the herring, *loses* water by osmosis through the gill semipermeable membrane. Sea water is drunk in large quantities and water enters the body by osmosis through the gut wall. Mineral ions are eliminated through *salt glands* in the gills.

The nitrogenous waste is mainly *urea* which leaves the kidneys in scanty *concentrated* urine.

Seawater fish therefore *retain* water, and *eliminate* excess mineral ions.

(d) Land-living animals

Land animals take in water as part of their food and drink to replace the water continually lost in *urine*, and by *evaporation* from the body surface and respiratory surfaces. There is a need to *conserve* water by various means; this is achieved by *waterproof* body coverings, and *reabsorption* of water from faeces in the large intestine and from urine in the kidney of mammals.

Birds and reptiles produce a *semi-solid* paste-like excretory waste consisting mainly of insoluble *uric* acid.

Mammals produce a *liquid urine* which is of a *greater* concentration than the tissue fluid.

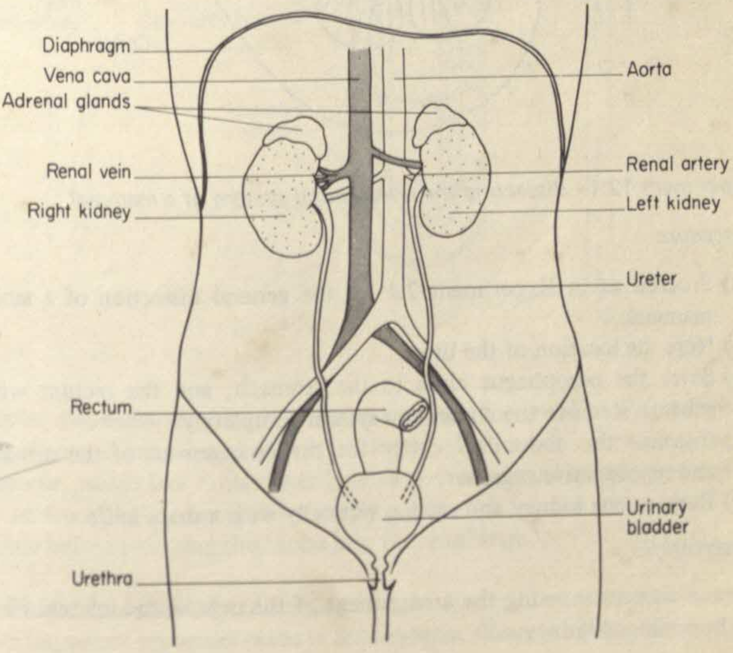
12.7 THE KIDNEY

The kidney is another organ in very *close contact* with the blood. The kidney is a *homeostatic organ* maintaining the concentration of water by *osmoregulation*, removing urea by *excretion*, and regulating the concentration of the blood mineral ions and also its pH, acidity or alkalinity.

(a) Mammal kidney structure

Two kidneys are located on the dorsal wall of the abdominal cavity. Each receives oxygenated blood from the *renal artery*, and blood is removed by the *renal vein*. Close to these blood vessels are the paired *adrenal glands* (Fig. 12.4).

fig 12.4 *the excretory or urinary system of a human female*

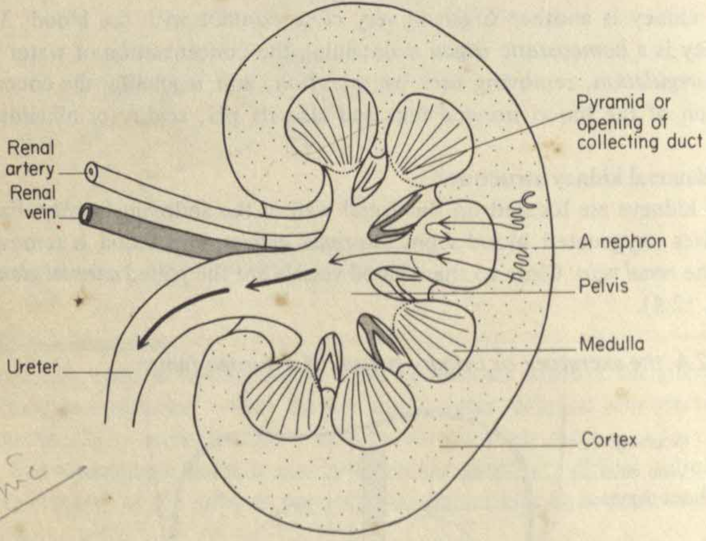


Positn

Tubular *ureters* convey urine by *peristalsis* from each kidney into the *urinary bladder*, which is emptied by way of the *urethra* during *micturition*. The urethra is controlled by a ring-like *sphincter* muscle.

Internally, each kidney has two regions, the outer *cortex* and inner *medulla*, with *pyramids* seen only in man connecting with a collecting space, the renal *pelvis* (Fig. 12.5).

fig 12.5 *a vertical section to show the internal structure of a human kidney*



Experiment 12.1 ***dissecting the urinogenital system of a mammal***

Procedure

(i) Proceed as in Experiment 7.4 for the general dissection of a small mammal.
(ii) Note the location of the liver.
(iii) Sever the oesophagus close to the stomach, and the rectum with scissors. Remove the alimentary system completely.
(iv) Examine the abdominal cavity for the arrangement of the urinary and reproductive organs.
(v) Remove one kidney and section vertically with a sharp knife.

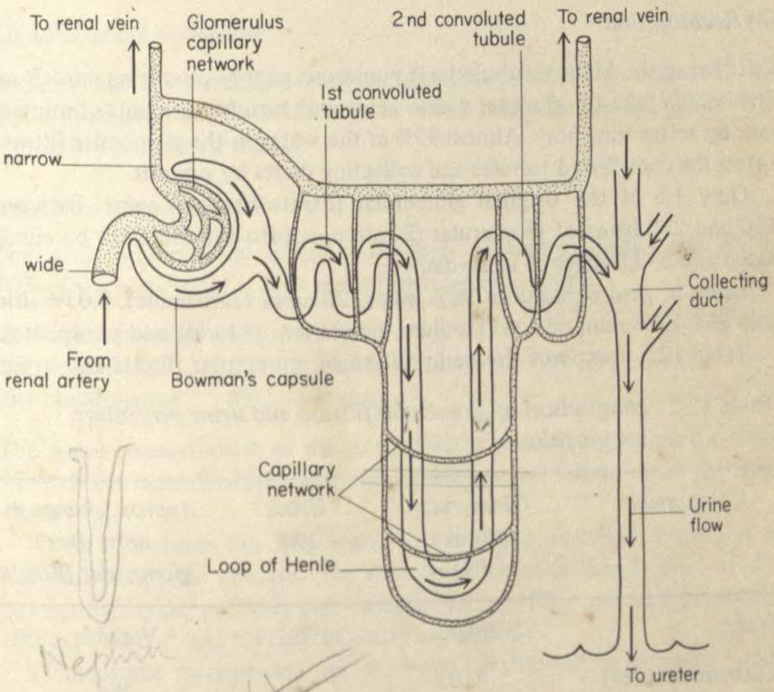
Observations

Draw a diagram showing the arrangement of the organs, and internal view of the sectioned kidney.

(b) The nephron

The *nephron* (Fig. 12.6) is the basic unit of the kidney, there being over a million in each kidney. The renal artery supplies an *afferent arteriole* which connects with a small bunch of blood capillaries called a *glomerulus* which projects inside a *Bowman's capsule.* Each Bowman's capsule is the blind end of the kidney *tubule* which is made up of a *first* convoluted tubule, *descending* and *ascending* tubules with a loop of Henle in between, and a *second* convoluted tubule leading to a *collecting duct*. An *efferent arteriole*, which has a narrower bore than the *afferent arteriole*, removes blood from the glomerulus to supply a network of blood vessels to the tubule before returning the blood into the *renal vein.*

fig 12.6 *the structure of a human kidney nephron*



Nephron

(c) Mechanism of kidney function

Two important processes occur in the nephron, *filtration* and *reabsorption.*

(i) *Filtration*

Blood pressure provides the *force* for blood plasma fluid to be filtered through the thin epithelium of the glomerulus, and the neighbouring Bowman's capsule wall, to produce the ***glomerular filtrate*** which enters the kidney tubule. The glomerular filtrate is blood plasma *without* blood cells and large-molecule proteins.

All the body blood passes through the kidneys 350 times a day, at the rate of 1.2 litres per minute. This produces 125 cm^3 of glomerular filtrate per minute.

When a kidney is *defective*, proteins pass into the glomerular filtrate.

(ii) *Reabsorption*

Cells lining the kidney tubule have numerous energy-producing mitochondria, which take up glucose, amino acids and *variable* amounts of mineral ions by active transport. Almost 99% of the water in the glomerular filtrate enters the convoluted tubules and collecting ducts by *osmosis.*

Only 1% of the original glomerular filtrate becomes *urine*. Between 170 and 200 litres of glomerular filtrate pass into the tubule to be eliminated as 1.5–2.0 litres of urine *daily*.

Urine in man consists of 96% water, 2% urea (carbamide), 0.03% uric acid and 1.4% mineral ions (sodium, potassium, chloride and phosphate).

Table 12.2 compares the composition of glomerular filtrate and urine.

Table 12.2 *comparison of glomerular filtrate and urine percentage composition*

Component	*Glomerular filtrate (%)*	*Urine (%)*	*Approx. change in urine over glomerular filtrate*
Water	98	96	Variable
Carbamide (urea)	0.03	2	×65
Glucose	0.10	nil	–
Proteins	nil	nil	–
Sodium chloride			
sodium ion	0.32	0.32	×1
chloride ion	0.30	0.60	×2
Potassium	0.02	0.15	×8
sulphate ion	0.003	0.18	×60

(d) Homeostatic function of the kidney

The kidney has *three* main homeostatic functions, in maintaining the pH, mineral ion and water composition of the blood fluid.

(i) *pH regulation*

The kidney tubule exchanges certain hydrogen or hydroxyl ions, to maintain the blood plasma fluid at a norm of pH 7.4. The exchanged ions in the urine cause it to be either acid at pH 5 or alkaline at pH 8. Urine pH can be shown by dipping a BDH Universal Indicator paper into a urine sample and matching the colour formed with the pH colour chart.

(ii) *Mineral ion regulation*

Sodium ions are controlled in a complex homeostatic process involving the adrenal gland hormone *aldosterone* which increases sodium ion absorption in the convoluted tubule.

(iii) *Water balance control*

The adult human body contains 45 litres of water which forms 65 to 70% of the body weight. This water is divided as follows:

(i) inside the cells: 66%, 30 litres;
(ii) tissue fluid: 26%, 12 litres;
(iii) blood plasma: 6%, 3 litres.

The water concentration of the *tissue fluid* is maintained within the range 97-99% (or mean 98%) by making the daily water *intake equal* the daily water loss.

Table 12.3 shows the daily water loss and gain, in a healthy person, at rest in a temperate climate. The *metabolic water* is the product of respiration of lipids, proteins and carbohydrates, 100 g of each producing 100 cm^3, 40 cm^3 and 60 cm^3 of water respectively.

Homeostatic mechanisms operate when insufficient or excessive water intake occurs.

(1) Insufficient water intake

(i) A shortage of water causes the water concentration to fall *below* the norm of 98%; this in turn causes the blood *osmotic pressure* to rise.
(ii) Sensory receptors in the brain (*hypothalamus*) detect the change in *osmotic pressure* and signal the *pituitary gland* by negative feedback (Section 13.11).
(iii) The pituitary gland (Section 13.13) sets off the corrective mechanism by secreting the *antidiuretic hormone* (ADH) or *vasopressin*; this

Table 12.3 *daily water loss and gain in man (in good health, at rest, in temperate climate)*

Loss (cm^3)		*Gain* (cm^3)	
1 By skin, sweat	500 (20%)	1 In drink	1500 (60%)
2 By lungs, exhalation	400 (16%)	2 In food	700 (28%)
3 In faeces	100 (4%)	3 Metabolic water, a product of respiration*	300 (12%)
4 In urine	1500 (60%)		
Total	= 2500 cm^3	Total	= 2500 cm^3

*Glucose + oxygen = carbon dioxide + *metabolic water*.

causes the kidney tubule to absorb *more* water. The urine becomes *scanty* and *concentrated.* Thirst develops and water is taken into the blood from the intestine, diluting the blood and returning the water composition to its norm of 92%.

(2) Excessive water intake

(i) Excessive water intake *increases* the tissue fluid water concentration *above* the norm of 98%; this causes the blood osmotic pressure to *fall*.

(ii) Sensory receptors in the brain detect the osmotic pressure change and signal the pituitary gland by negative feedback.

(iii) The gland sets off a corrective mechanism which *stops* the gland secreting ADH or vasopressin. No more water is absorbed in the tubules, and the urine becomes copious and dilute. The tissue fluid concentration decreases and returns to the norm of 98% and blood osmotic pressure rises to its norm.

Water diabetes is due to defective water control through *positive feedback* and lack of ADH or vasopressin secretion. This causes production of large volumes of dilute urine and of thirst, leading to body *dehydration*.

Oedema or *dropsy* is the accumulation of water in body tissues.

12.8 OSMOREGULATION IN PLANTS

There are no specific osmoregulation organs in higher plants. Control of water intake and loss is by means of those internal and external *factors* which affect the rate of *transpiration*.

Plants share with animals the problems of *obtaining* water, and in *disposing* of the surplus. Certain plants develop methods of water conservation.

Xerophytes are plants in dry habitats, deserts, which are able to withstand prolonged periods of water shortage. *Succulent* plants, such as the cacti have water stored in large parenchyma tissue.

Other plants have *leaf modifications* to reduce water loss, such as needle-shaped leaves, sunken stomata and thick waxy cuticles as in the pine. The sand-dune marram grass has rolled leaves with stomata on the inner surface.

12.9 THE SKIN

(a) Structure

Skin (Plate 12.1) is one of the largest organs in the mammal body, having an area of between 1.5-2.0 m^2 in adult man, and providing a continuous *covering* to the body.

Mammal skin is composed of two main layers, the *epidermis* and *dermis* (Fig. 12.7).

(i) *Epidermis*

This is the surface layer *without* blood or lymph vessels, consisting of epithelial cell layers.

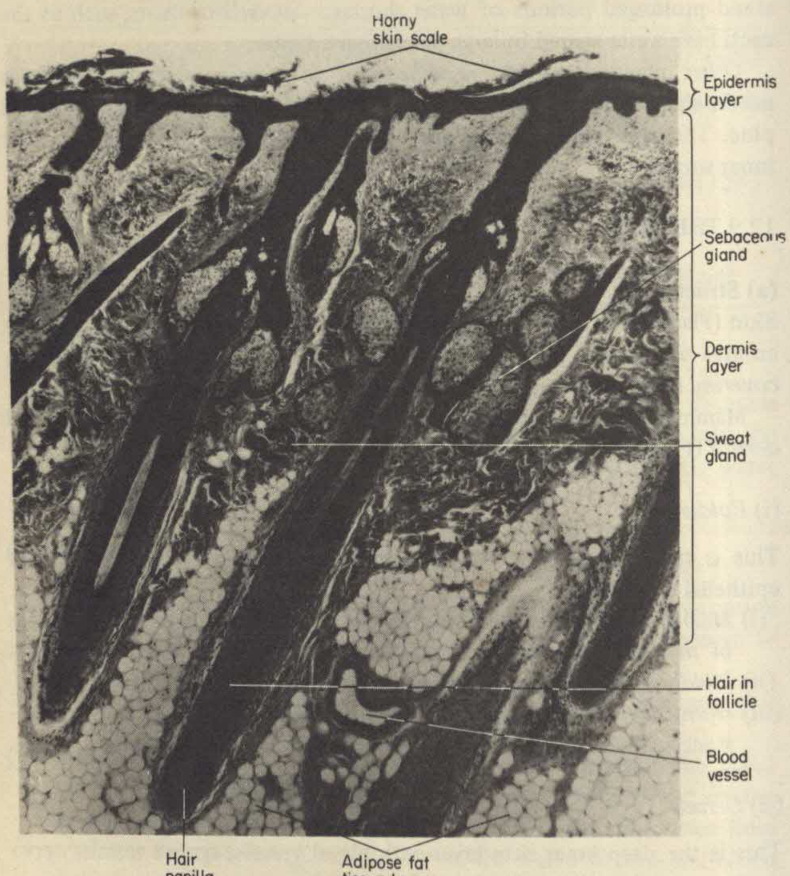
(i) *Malpighian layer* is composed of actively dividing cells with granules of *melanin* pigment. It forms the inner boundary with the dermis.
(ii) *Middle layers* are called the prickle, granular and clear layers.
(iii) *Horny layer* is composed of flaking scales of *keratin*, a protein substance which is also the component of hair and finger nails.

(ii) *Dermis*

This is the deep inner skin layer with blood vessels, lymph vessels, nerve endings, muscles, sweat glands and hair follicles.

(i) *Hair* fibres are in hair follicles with a hair papilla providing growth and pigment materials from a small capillary network. The *erector muscle* is attached between the papilla and epidermis; its contraction causes the hair fibre to move *upright*, and 'goose pimples' appear on the skin surface.
(ii) *Sebaceous glands* produce a secretion of sebum, a mixture of lipid and waxy substances, having emollient, lubricating, waterproofing and bactericidal properties.
(iii) *Sweat glands* which end blindly have a long duct opening onto the skin surface by pores. A blood capillary network supplies the components of sweat: 99% water, 0.1–0.4% sodium chloride, 0.015%

plate 12.1 *a photomicrograph of mammal skin, seen in vertical section, showing the main structures (Griffin Biological Laboratories)*

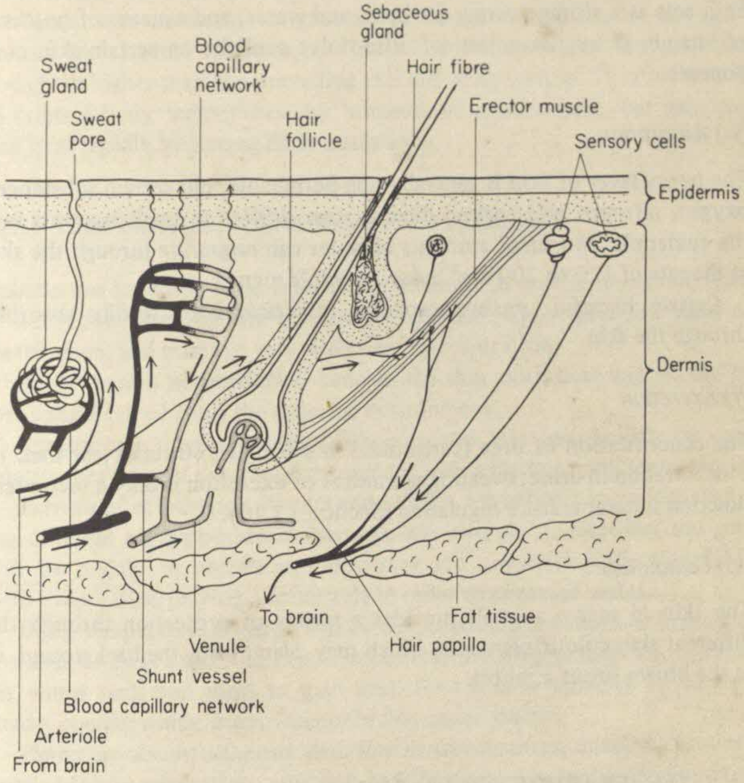


carbamide (urea) and small amounts of vitamins B_1, C_1 and lactic acid.

(iv) *Blood capillaries* are found beneath the epidermis formed from an arteriole and venule. An *arterial shunt* vessel may bypass the capillary network in the skin of ears, nose and finger tips.

(v) *Subcutaneous fat* depots of lipid *adipose* tissue also insulate the body. *Brown* fat layers are seen in young newborn and hibernating mammals. These are heat-generating tissues.

fig 12.7 *a vertical section of human skin to show its internal structure*



(vi) *Sensory cells* receive sensations of heat, cold, touch and pain. A network of nerve fibres surrounds the hair fibre, making 'whiskers' sensitive to touch. A nerve fibre supplies the erector muscles.

(b) Skin functions

Skin has several functions:

(i) *Protection*

Skin acts as a barrier between the internal and external environment in body defence described in Section 19.7.

(ii) *Sensation*

Sensory function makes the body aware of *changes* in the external environment through touch, pain, pressure, heat and cold sensory cells.

(iii) *Storage*

Skin acts as a storage centre for lipids and water, and a means of *synthesis* of vitamin D by the action of ultra-violet sunlight on certain skin components.

(iv) *Absorption*

The horny layer of skin is generally non-permeable, but certain substances, oxygen, nitrogen and carbon dioxide, can *diffuse* in small amounts into the epidermis, and small amounts of water can *evaporate* through the skin at the rate of 120 to 200 cm^3 a day for adult man.

Certain harmful organophosphorus *insecticides* are readily absorbed through the skin.

(v) *Excretion*

The concentration of urea (carbamide) in sweat is 130 times less than its concentration in urine; sweating as a means of excretion is only a secondary function to temperature regulation (Section 12.10).

(vi) *Camouflage*

The skin in many animals provides a means of protection through the different skin colour pigments, which may *blend* with the background, as in the brown fur of a rabbit.

12.10 TEMPERATURE REGULATION

Living organisms can survive within a temperature range from 0 to 45°C. Above 45°C the *enzymes* are destroyed, proteins are denatured, plasma membranes break down and cells suffer lack of oxygen. Below 0°C the cells burst by formation of needle-like *ice* crystals within and between the cells.

A constant body temperature of 37°C is favoured by most animals since this is the *optimum temperature* for efficient *enzyme* action within and outside of cells.

(a) Endotherms

Endotherms, also called *homoiotherms*, include birds and mammals, and are able to *generate* their heat *internally*, and maintain their body temperature within a narrow range of 2°C (37-39°C) by *homeostatic* mechanisms, and by *good insulation.*

(b) Ectotherms

Ectotherms, also called *poikilotherms*, include all animals *except* birds and mammals, who are unable to generate sufficient body heat, but must *gain* it from the external environment. Their body temperature fluctuates and is slightly higher than the prevailing external temperature. They are *unable* to control body temperature by homeostatic mechanisms, but gain and lose heat rapidly by having little insulation.

12.11 TEMPERATURE CONTROL IN ECTOTHERMS

Ectotherms have *low* food intake. For example, a reptile needs only 10% of the food eaten by an equal-sized mammal. They have *low* rates of metabolism, and produce very *little heat* by respiration.

Since there is no *insulation* beneath the thin skin, heat will readily be lost to and gained from the external environment.

Aquatic ectotherms, such as fish, gain and lose heat mainly by conduction between an external environment with a fairly steady temperature.

Terrestrial ectotherms, insects and reptiles, are subject to rapidly changing external air temperatures between day and night. Heat loss and gain will be mainly by *radiation*, *convection* and *conduction* (Section 5.11) with evaporation playing a lesser role in order to conserve water.

Body temperature *control* will be by the animal's *behaviour* in *moving* towards or away from the heat source. This involves sunbathing, or lying on warm rock and sand to gain heat. Heat loss is achieved by seeking shade, cooling winds, burrowing or hiding under stones.

Plants are also ectotherms with *low* metabolic rates, unable to produce much heat by respiration, and *gain* heat from the external environment as seen in heated greenhouse plant culture.

12.12 TEMPERATURE CONTROL IN ENDOTHERMS

Endotherms have a *high level* of food intake to provide heat and body energy by a *high* rate of metabolism. Half the energy produced in cell respiration is *heat* energy. *Body heat* comes mainly from cell respiration, 50%, muscle activity, 38%, and the liver functions, 12%.

Birds and mammals have *good insulation* from hair, feathers and subcutaneous fat.

Under normal conditions the body temperature will be maintained at 37°C by self-regulating *homeostatic* mechanisms.

Endotherms gain the following advantages in having a steady body temperature.

(i) Steady *rate* of chemical and enzyme activity.

(ii) Endotherms can be *active* at any time of day, compared to ectotherms who are inactive at night.
(iii) Endotherms can inhabit cold polar climates, but are not so numerous in hot desert climates where ectotherms thrive.

(a) Heat control in overheating

Endotherms can control their body temperatures by the following *physiological* and *behavioural* methods.

(i) *Physiological methods*

Less insulation is achieved by having *less* subcutaneous fat in warm climates. The hair or feathers lie flat on the skin surface by *relaxation* of the erector muscle; this reduces the layer of *air* insulating the body, allowing heat loss.

Vasodilation is the expansion of the *arterioles*, providing *more* blood to the skin capillaries; this encourages heat loss by radiation.

Evaporation of 1 cm^3 of water, or sweat, requires 2.4 kJ of heat. Sweat glands produce between 600 cm^3 in a body at rest up to 8000 cm^3 in a body working in the tropics. Therefore between 1440 kJ and 19 000 kJ (19 MJ) can be lost per day through sweat evaporation, depending on climate and physical activity.

Panting encourages water evaporation from the tongue and lung surfaces. In normal breathing, 400 cm^3 of water evaporates, equal to 950 kJ of heat per day.

Metabolism and muscle activity are slowed down. This results in a *lower* food intake, and less heat from muscle and liver activity. Cold food and drink can help to reduce overheating.

(ii) *Behavioural methods*

Overheated animals will seek shade, bathe or wallow in water. Man will reduce the amount of outer *clothing*.

(b) Heat control in overcooling

(i) *Physiological methods*

More insulation is achieved by laying down *more* subcutaneous fat as *blubber* in whales and animals about to overwinter. Hair and feathers are raised by *contraction* of erector muscles, increasing the insulating layer of air and retaining body heat.

Vasoconstriction is the narrowing of skin arterioles, reducing blood flow to skin capillaries. The blood may bypass the skin surface capillaries by the *arterial shunt* in the skin of body extremities, nose and ears.

Evaporation by sweating is stopped by vasoconstriction of blood vessels to sweat glands.

Metabolism and muscle activity is increased. There is an increased intake of food, leading to a higher metabolic rate in the liver and body tissues. Muscles produce heat, first by contracting and then by involuntary 'shivering'.

(ii) *Behavioural methods*

Overcooled animals will huddle together, curl up into a ball, or retire to burrows and nests to keep warm in a static 'fug'. Migration and hibernation are also means of avoiding unfavourable changes of climate.

Man adjusts to overcooling by wearing more clothing or doing physical exercise.

(c) Body size in heat control

Small animals or body parts will have a *high* surface area/volume ratio, or have *more* skin compared to body volume. Consequently, there will be more heat loss from small *exposed* animals, or body parts, such as ears and noses. Small endotherm animals such as the shrew have a *high* food intake and high metabolic rate. A shrew consumes its own weight of food in 24 h. In cold, unfavourable conditions, the shrew is unable to maintain the high metabolic rate and has the need to *hibernate*. Its lifespan is short, 12–18 months.

Large endotherms, such as the elephant, have a *low* surface area/volume ratio, or have *less* skin to body volume. Consequently, they have less heat loss per unit volume. The nose and ears are large and are used to *radiate* heat from the body, whereas the shrew has smaller ears and nose *close* to the body. Elephants have a moderate food intake, to supply a lower metabolic rate. They have ample lipid and energy reserves to face unfavourable conditions without hibernation. Lifespan is 50–80 years.

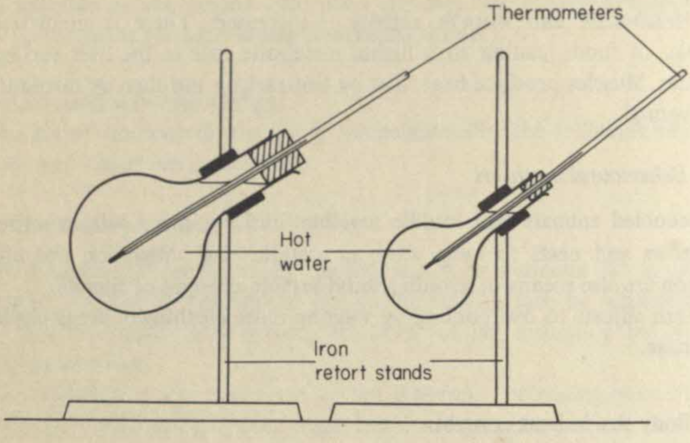
Newborn mammals and birds will experience *heat loss* from their high skin surface area/volume ratio, and will need to gain heat from the external environment in the nursling stage. The *brown fat* present in some newborn mammals, including man, is believed to *generate* heat by metabolism, in a manner resembling a heating blanket.

Experiment 12.2 *to compare heat loss from different sized surfaces* (Fig. 12.8)

Procedure

(i) Obtain two round-bottomed flasks of different capacity, say 50 cm^3

fig 12.8 *experiment to demonstrate the relationship between surface area and heat loss from large and small bodies*



and 25 cm^3; each represents 'animals' of different body volume. Fit each flask with a 0–100°C thermometer and rubber stopper.

(ii) Fill each flask with boiling water from an electric kettle. Support the flasks in air by means of retort stands and clamps.

(iii) Record the temperatures of water in each flask every 5 min.

Observations

A graph may be constructed to display the fall in temperature of each flask. The small flask has a greater surface area/volume ratio and shows a more rapid fall in temperature. Both flasks would represent ectotherm animals without heat loss controls.

12.13 HOMEOSTATIC TEMPERATURE CONTROL IN ENDOTHERM ANIMALS

The automatic self-regulating mechanism of heat control in birds and mammals operates through the nervous system and by hormones from the pituitary, thyroid and adrenal *glands* (Section 13.13)

Sensory detectors in the skin and inside the body relay information by *negative feedback* to the *central* temperature control located in the brain called the *hypothalamus* (Section 13.11).

The brain hypothalamus is similar to a machine *thermostat* and is itself sensitive to changes in blood temperature which bathes the hypothalamus. It is responsible for setting off *corrective* mechanisms when the blood temperature rises or falls.

(i) *Blood temperature rises* and the adrenal gland secretes various hormones, resulting in *vasodilation*, increased skin blood supply and sweating. The muscles *relax* and hair lies flat, resulting in heat loss and body temperature being restored to the norm of 37°C.

(ii) *Blood temperature falls* and the thyroid gland secretes *thyroxine* hormone. This increases the metabolic rate, muscles contract and twitch, hair is raised, *vasoconstriction* occurs with decreased skin blood supply and sweating stops.

Positive feedback occurs in *defective* homeostatic control. Blood temperature will continue to fall, with lowered metabolic rate, and death occurs at body temperatures below 26°C by *hypothermia*. Hypothermia occurs in elderly people and young babies in unheated rooms in wintertime. Hypothermia is also induced intentionally for open heart surgery.

A rising blood temperature may occur when the body is unable to correct temperature over 41°C. Increased metabolic rates lead to higher body temperatures. Death occurs at body temperatures above 43°C by *hyperthermia* or heat stroke.

12.14 QUESTIONS

1 By means of a labelled diagram, describe the structure of mammal skin. Show how the skin functions in maintaining a constant body temperature.

2 Describe the gross structure of the mammal urinary system, and describe the structure and function of a nephron. What are the four main components of urine, and what are their origins in the mammal body?

3 Summarise the different ways in which a healthy human body gains and loses water.

4 Explain each of the following terms with respect to the control of blood sugar in mammal blood: (a) tissue fluid; (b) norm or set point; (c) negative feedback; (d) homeostasis.

5 Compare and contrast the methods of heat control available for a frog and a rabbit.

CHAPTER 13

IRRITABILITY

13.1 STIMULUS

Irritability is that property of living things in being *aware* of, and being able to *respond* to, a *stimulus.*

Plants may show growth movements (Section 11.10), or movements due to cell turgor changes (Section 9.2), or protoplasmic streaming movements (Section 9.1), in response to various stimuli. *Animals* show different movements as a result of *nervous* activity in response to stimuli.

A *stimulus* is a physical or chemical *change* in part or whole of an organism's internal or external environment causing a change in its *activities.*

Physical stimuli include changes in temperature, pressure, light, sound and electrical *intensities.*

Chemical stimuli include changes in pH (acidity or alkalinity), or concentration of water, salts or organic compounds in foods or producing tastes or odours from various secretions

13.2 NERVOUS SYSTEMS

(a) Simple nervous systems

(i) *Amoeba*

Amoeba shows irritability in being able to *receive* a stimulus, *transmit* it to another part of the cell, and to *effect* a *response. Amoeba* moves *away* from irritant chemicals, strong light and sharp objects, and moves *towards* food particles.

The stimulus is received by *receptors* in the plasma membrane, or plasmalemma, each receptor being sensitive to a *specific* stimulus, pressure, chemicals, etc., and produces an *impulse.* The impulses pass across the cytoplasm to connect with the *effector* which causes a pseudopodium to form. In *Paramecium* the effector stimulates the cilia. The change seen in the *pseudopodium* or cilia causes movement seen as a *response*.

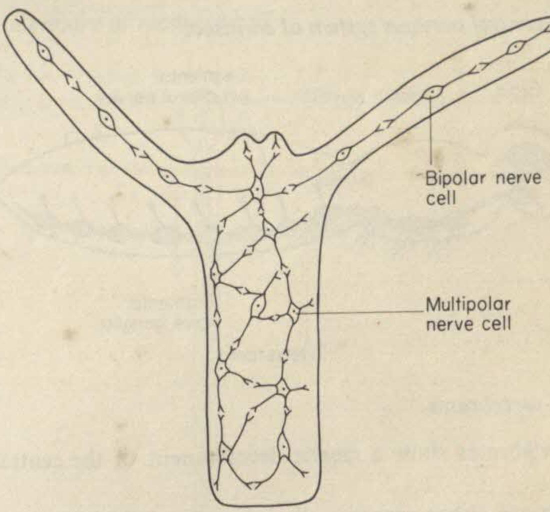
$$\text{stimulus} \longrightarrow \text{receptor} \xrightarrow[\text{transmission}]{\text{impulse}} \text{effector} \longrightarrow \text{response}$$

(ii) *Hydra*

Multicellular animals have a *nervous system* composed of nerve cells called *neurones* (see Fig. 3.5).

Receptors or *sensory cells* are located in the *Hydra's* ectoderm and connect *directly* with a network (Fig. 13.1) of neurones in the mesoglea.

fig 13.1 *the nerve net of a* Hydra *sp.*



Impulses travel from the receptors, along the neurones, to stimulate the effectors; these are *gland, muscle* or *sting* cells. The activity of these cells results in *different* responses:

(i) digestive juice secretion;
(ii) tentacle movements;
(iii) body movements;
(iv) release of sting.

The *network* of neurones is *coordinating* or linking together *physiological* activities such as digestion, and *behavioural* activities seen as movement. This neurone network is a simple nervous system.

$$\text{stimulus} \longrightarrow \text{receptors} \xrightarrow[\text{system network}]{\text{simple nervous}} \text{effectors} \longrightarrow \text{response}$$

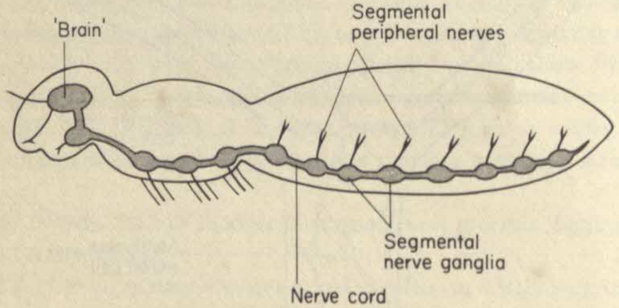
(b) Complex nervous systems

(i) *Insects*

Insects have receptors of either sensory *cells* or sensory *organs*, connected by nerves to a *central* nervous system (Fig. 13.2), composed of a *nerve cord* and *brain.* This links by nerves to different effectors.

$$\text{stimulus} \longrightarrow \text{receptors} \xrightarrow[\text{nervous system}]{\text{complex central}} \text{effectors} \longrightarrow \text{response}$$

fig 13.2 *the central nervous system of an insect*



(ii) *Man and vertebrates*

Man and vertebrates show a greater development of the central nervous system.

Receptors are either sensory cells or organs, linked by nerves to the *central nervous* system, composed of a spinal cord and brain. In contrast to invertebrates, the spinal cord and brain occupy a *dorsal* position, compared to the *ventral* position of invertebrates.

The *endocrine system*, which produces hormones, has an important function in *coordination* in working together with the central nervous system. The combined activity results in a *neuroendocrine system*. Muscle and gland activities are coordinated by the nervous system, whilst *chemical* metabolic activity is coordinated by the endocrine system.

$$\text{stimulus} \longrightarrow \text{receptors} \xrightarrow[\text{system}]{\text{neuroendocrine}} \text{effectors} \longrightarrow \text{response}$$

13.3 RECEPTORS

Receptors are those parts of an animal connected with the nervous system to detect changes in the external and internal environment. They are of two main types:

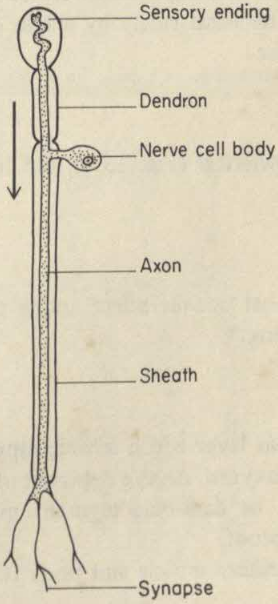
(i) *exteroreceptors*, which respond to *external* stimuli and are found in skin, nose, tongue, eye and ear sensory organs;

(ii) *interoreceptors*, which respond to *internal* stimuli such as changes in chemical concentration of *tissue fluid* (Section 12.1) or physical changes such as in tension of muscles.

(a) Sensory cells

The *sensory cell* is the structural unit of receptors (Fig. 13.3), many similar or different sensory cells being grouped together in a sense *organ*.

fig 13.3 *a sensory or receptor cell*



A simple sensory cell is a cell structure somewhat similar to a *neurone* (see Section 13.10). A nerve *cell body* containing a *nucleus* connects with a dendron whose sensory ending receives the stimulus, which is passed to the axon ending in synapses.

(b) Functions of sensory cells

The *energy* of the stimulus, i.e. heat, light, pressure or chemical, is *changed* into *electrical energy* by the sensory cell acting as an *energy transducer.*

Interpretation: sensory cells are only able to act in *sensing* a stimulus and producing *impulses* (see Figs. 3.5, 11.12, 11.13, 12.7 and 13.5).

13.4 THE HUMAN EYE

(a) Structure of the eye

(i) *Surrounding structures*

The eye *orbits* are cavities in the skull housing the *eyeballs* which are connected by six muscles that allow different eye movements.

The *eyelids* are skin folds which protect the eye front and distribute the tear fluid. The *conjunctiva*, the innermost lining of the eyelid, completely covers the eyeball front *except* for the cornea.

Tear glands secrete the tear fluid which either *evaporates* from the eye surface or drains into the nasal cavity by a tear *duct*, after cleaning and lubricating the eye surface.

(ii) *The eyeball*

The eyeball is almost *spherical* (Fig. 13.4) and has a wall composed of three coats.

(1) Outer coat

This consists of an almost opaque *sclera* and a transparent cornea connected in a continuous ring.

(2) Middle coat

This consists of a *choroid* layer which is well supplied with blood vessels providing nutrients and oxygen. An eye deprived of oxygen will be irreparably damaged. A black or dark-blue pigment makes the choroid layer totally opaque and lightproof.

The *circular iris* and *ciliary* muscle and body form the front portion of the middle coat.

(3) Inner coat

The inner coat or *retina* consists of millions of sensory cells, called the *rods* and *cones* (Fig. 13.5). There are 20 times the number of rods than cones in the human retina.

fig 13.4 *a vertical section through a human eye to show its internal structure*

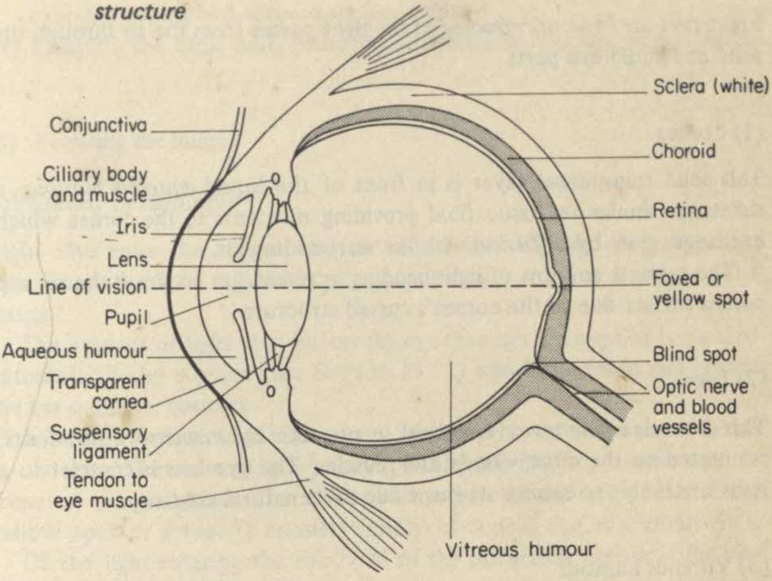
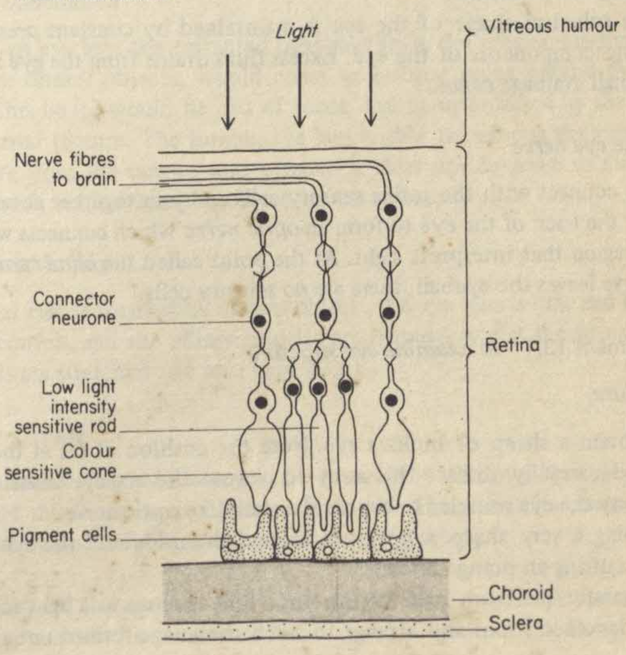


fig 13.5 *the two main kinds of sensory cell present in the human retina, rods and cones*



(iii) *The transparent and light-refracting parts*

Light rays are *bent* or *refracted* as the light passes from the air through the solid and liquid eye parts.

(1) Cornea

This solid transparent layer is in front of the liquid *aqueous humour*, a substance similar to tissue fluid providing nutrients to the cornea which exchanges gases by *diffusion* with the surrounding air.

The greatest amount of light bending or *refraction* occurs at the air and cornea surface due to the cornea's curved structure.

(2) Lens

This is a clear *biconvex* lens held in position by *suspensory ligaments*, connected to the *ciliary body* and muscles. The eye lens is contrast to a glass lens is able to *change* its shape due to its natural elasticity.

(3) Vitreous humour

A clear jelly-like *vitreous humour* completely fills the eyeball behind the lens and ciliary muscles.

The spherical shape of the eye is maintained by constant *pressure* of the fluid components of the eye. Excess fluid drains from the eye interior by a small drainage *canal*.

(iv) *The eye nerve*

Nerves connect with the retina sensory cells and join together at one position at the back of the eye to form an *optic nerve* which connects with the brain region that interprets sight. At the point called the *blind spot* where the nerve leaves the eyeball, there are *no* sensory cells.

Experiment 13.1 *to examine eye structure*

Procedure

(i) Obtain a sheep or bullock eye. Note the cushion of fat at the back, and carefully dissect this away to expose the six eye muscles. Cut away the eye muscles to expose the stalk-like optic nerve.

(ii) Using a very sharp scalpel, cut around the middle of the eyeball, as in cutting an orange in half.

(iii) Examine the front half for the lens. Hold it close to a light source in a darkened room and arrange to catch the image formed onto a sheet of greaseproof paper held behind the eye. Remove the lens and examine the iris and suspensory ligaments.

(iv) Examine the back half, removing the vitreous humour with forceps.

(b) Focusing the image

(i) *Pathway of light rays*

Light rays enter the cornea and are refracted at the air–cornea surface; this causes the light rays to *converge* and finally meet at a point on the retina.

The amount of light that enters the eye through the *pupil* is controlled automatically by a *reflex* (see Section 13.12) which contracts and relaxes the *iris* sphincter *muscles.*

After slight refraction in the aqueous humour, the light rays are refracted by the *lens*. The converging light rays pass through the vitreous humour to *focus* on the eye retina. The most sensitive part of the retina is called the yellow spot or *fovea*. It consists mainly of cones, and is without rods.

Of the light entering the eye, 70% of the refraction occurs at the air–cornea surface, and 30% in the lens.

(ii) *Accommodation*

Without an eye lens the refracted light rays from the cornea, reaching the eye from *distant* objects, would come to a focus point *behind* the eye retina. This image would be out of focus, and be interpreted by the brain as a *blurred* picture. The human eye lens is able to refocus the refracted light rays from the cornea and produce a clear upside-down or *inverted* image, much smaller than the object, on the retina.

(1) Distant viewing

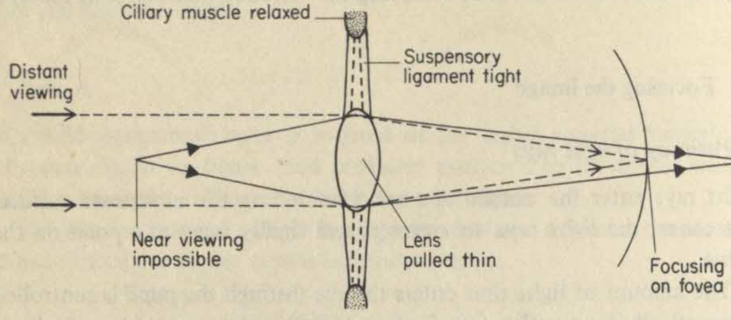
An eye at *rest* is focused on *distant* objects, the eye lens is *thin* and flatter or less convex, and the ciliary muscles are *relaxed*, whilst the suspensory ligaments are stretched and *taut* (Fig. 13.6).

(2) Near viewing

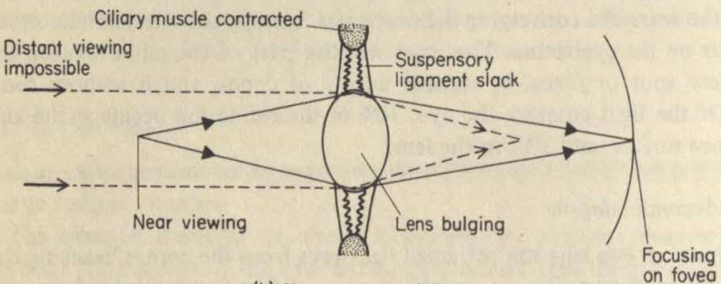
Objects within 3 m of the eyes are focused by the eye lens becoming *fatter* and shorter or more convex, and by the ciliary muscles *contracting*, causing the suspensory ligaments to *slacken* (Fig. 13.6).

This ability of the eye to adjust its lens focusing power for distant and near objects is called *accommodation*.

fig 13.6 *methods of eye lens focusing or accommodation*



(a) Distant accommodation


Ciliary muscle contracted
Distant viewing impossible
Suspensory ligament slack
Near viewing
Lens bulging
Focusing on fovea

(b) Near accommodation

(iii) *Eye defects*

(1) Longsightedness – hypermetropia

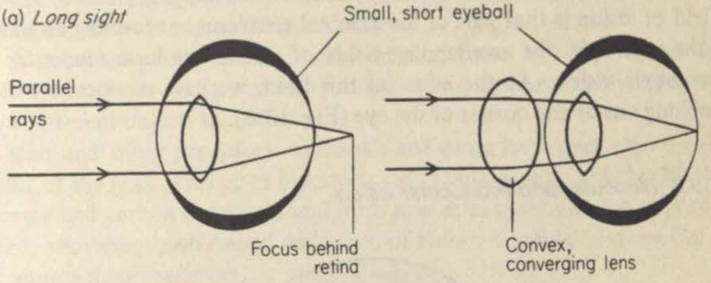
This is caused by a *short* eyeball or loss of lens elasticity. Light rays from distant objects come to focus on a point *behind* the retina. The ciliary muscles are never at rest and are continually contracting in order to allow the person to read at close quarters. It is corrected by converging or *convex* lenses (Fig. 13.7).

(2) Shortsightedness – myopia

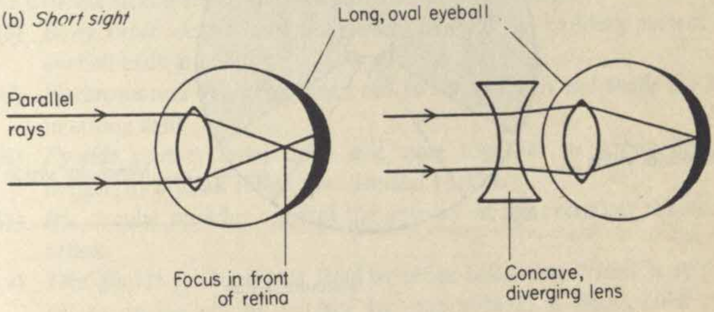
This is due to a *long* eyeball or increased corneal *curvature*. Light rays from distant objects come to focus on a point in *front* of the retina in the vitreous humour. It is corrected by wearing diverging or *concave* lenses in spectacles (Fig. 13.7).

fig 13.7 *eye defects and correction by different lenses*

(a) *Long sight*



(b) *Short sight*



(c) Retina functions

(i) *Light sense*

Dim light of *low intensity*, or black and white light, is sensed by the *rod* sensory cell. The rods are present in greater numbers around the edges of the retina, and absent from the fovea, macula or yellow spot.

At night time, vision of dim lights may be improved by looking at them through the corner of the eye. Vitamin A, retinol, is an important nutrient to aid night vision. It is needed for the formation of *visual purple* by the rod cells. This substance is bleached by light, and increases in amount in darkness, making the rods more sensitive to dim light.

(ii) *Colour sense*

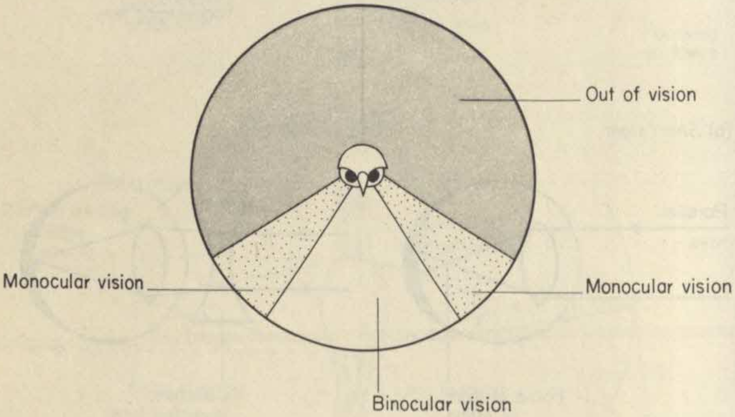
The component colours of white light are red, orange, yellow, green, blue, indigo and violet. *Red, green* and *blue* are primary colours, sensed by the *cone* sensory cells. The fovea, or macula, consists entirely of *cones.*

Colour blindness is an inherited disorder of certain cone sensory cells.

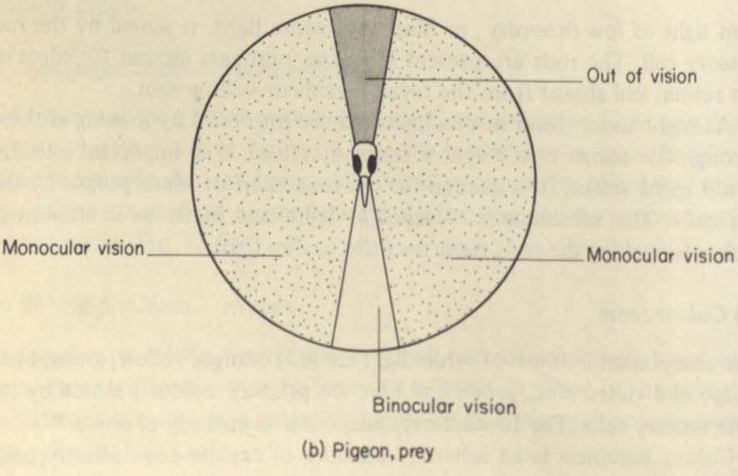
(d) Binocular vision

Eyes looking straight ahead at an object have overlapping *fields of vision*. A field of vision is that part of the external environment forming an image on the retina. In the overlapping fields of vision, we have *binocular* or stereoscopic vision. At the edges of this field, we have *monocular* vision in looking out of the corner of the eye (Fig. 13.8).

fig 13.8 *binocular and monocular vision*



(a) Owl, predator



(b) Pigeon, prey

In binocular vision, the eyes receive *slightly* different images of the object. These are interpreted in the brain to produce a picture with a sense of *depth, distance* and the third *dimension.*

A one-eyed person will not have binocular vision and experiences vision as a sense of *size* and *perspective*, depth being determined by lining up to two different objects by *parallax*.

Man and other *predatory* mammals and birds have eyes placed to the *front* of the head. This gives binocular vision with ability to judge *distance*. Horses and certain mammals and birds have eyes placed to the *sides* of the head, providing an *all-round* wide field of vision, valuable in giving warning of approaching *predators*.

(e) Eye protection and care

The delicate structures of the eye are protected as follows:

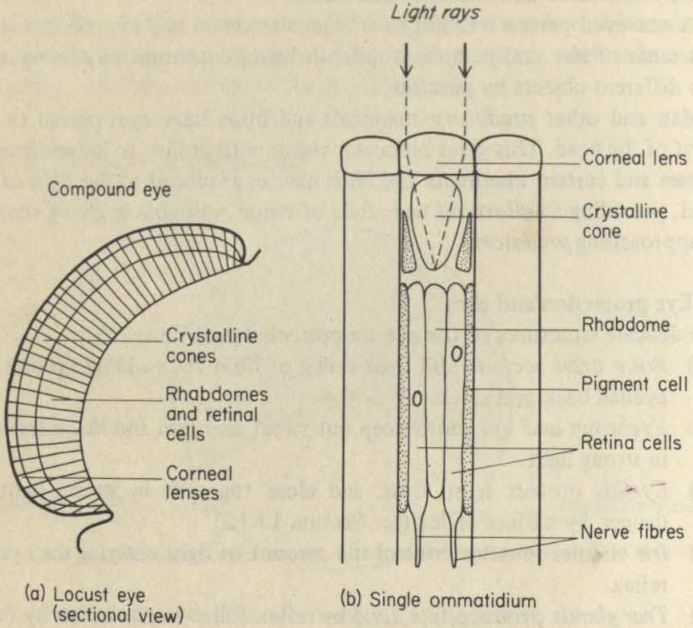
(i) *Bony orbit sockets* and their lining of lipid fat padding protect the eyeball back and sides.
(ii) *Eyebrows and eyelashes* keep out sweat and rain and *shade* the eyes in strong light.
(iii) *Eyelids* protect from dust, and close together in strong light or danger, by a blink reflex (see Section 13.12).
(iv) *Iris* circular muscles control the amount of light entering the eye by reflex.
(v) *Tear glands* produce tear fluid by reflex following *irritation* by dust, or on drying of the surface by *evaporation*. A bactericidal component, lysozyme, destroys airborne bacteria landing on the eye surface.
(vi) *Diets* should contain sufficient vitamin A, retinol, for night vision, and glucose for energy provision.
(vii) *Ultra-violet* and *infra-red* radiations damage the eye lens and retina. This is prevented by not looking into the Sun, sunlamps, heat lamps or furnaces and by wearing protective goggles.

13.5 THE INSECT EYE

(a) Compound eyes

Insects have two large compound eyes, each composed of a great number of light-sensitive units called *ommatidia* (Fig. 13.9). When viewed at the eye surface, these units appear as six-sided *lenses* fitting closely together, each receiving a *portion* of the image of an object. In contrast, the human eye receives *all* the image.

Each *ommatidium* consists of a *lens* and *crystal cone*, both of which refract light rays down a *rhabdom* to stimulate the surrounding light-fig 13.9 *(a) the structure of an insect compound eye and (b) its ommatidium*



(a) Locust eye (sectional view)

(b) Single ommatidium

sensitive cells or *retinal* cells. Impulses are transmitted to the brain where a composite blurred *mosaic image* is produced from combining each ommatidium impulse.

Insects have *fixed*-focus lenses, sensitive to all slight movements in the environment. Those insects that visit flowers have colour vision.

(b) Simple eyes

The simple eyes or *ocelli* are light-sensitive and resemble a single ommatidium. They are in adult insects, e.g. housefly, close to the compound eyes, and are present in insect larvae such as caterpillars.

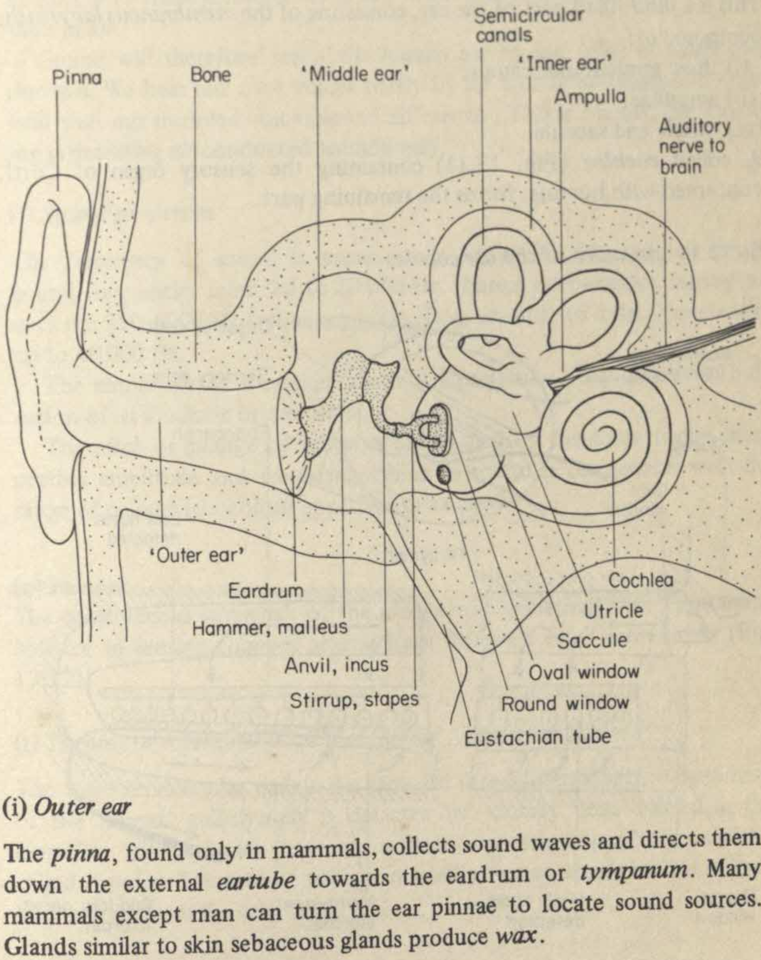
13.6 THE HUMAN EAR

The main functions of the human ear are in sensing *sound* and changes in the body *position* in maintaining *balance.*

(a) The structure of the ear

The ear structure (Fig. 13.10) may be considered in three parts: *outer, middle* and *inner* ear.

fig 13.10 *a simplified version showing the structure of a human ear*



(i) *Outer ear*

The *pinna*, found only in mammals, collects sound waves and directs them down the external *eartube* towards the eardrum or *tympanum*. Many mammals except man can turn the ear pinnae to locate sound sources. Glands similar to skin sebaceous glands produce *wax*.

(ii) *Middle ear*

This air-filled cavity communicates with the pharynx by the *eustachian tube*, and it allows air pressure on either side of the eardrum to be equalised. Yawning and swallowing help to open the eustachian tube.

Sound waves cause vibration of the eardrum. This vibration is transmitted by *three auditory ossicles*, hammer (malleus), anvil (incus) and stirrup (stapes) bones. The stirrup bone fits into the *oval window*.

Sound energy from the eardrum on reaching the oval window has a pressure between 17 to 30 times that on the eardrum.

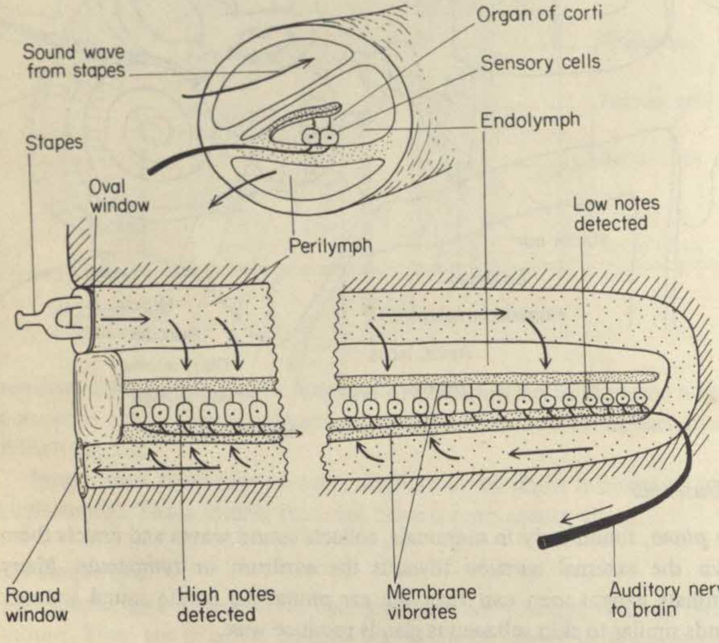
(iii) *Inner ear*

This is a *fluid*-filled part of the ear, consisting of the *membranous labyrinth*, composed of:

(i) three semicircular canals;
(ii) ampullae;
(iii) utricle and saccule.

A coiled *cochlea* (Fig. 13.11) containing the sensory organ of Corti, concerned with hearing, forms the remaining part.

fig 13.11 *structure of the ear cochlea*



Fluid within the inner tubes of the ear is *endolymph*. The outer fluid surrounding the tubes is called *perilymph*.

Sound pressure enters the inner ear by the *oval window* and after stimulating the different sensory cells emerges from the inner ear by the *round window.*

(b) Hearing

Sound is a form of energy. Vocal cords in the *larynx* are made to vibrate by transferring energy to them from moving air, the resulting sounds forming the human voice.

Sound is *conducted* through air, water and solids. The speed of sound in iron is 15 times greater than in air, whilst in water it is five times greater than in air.

Sound will therefore reach the human ear by *air, bone* or *water conduction.* We hear our *own* voices partly by *air* and *bone* conduction, and find that our recorded voices sound differently. This is because the recording is detecting *air*-conducted sounds only.

(i) *Sound properties*

The *frequency* of sound is measured in *hertz*, Hz. Human ears detect sound frequencies from 20 to 20 000 Hz. Human conversation takes place over the 250-6000 Hz frequency range. Dogs are able to detect frequencies up to 40 000 Hz.

The *amplitude* of a certain sound at a particular frequency is an indication of its *loudness* or *quietness*.

The *pitch* or *quality* of sound is determined by the brain region interpreting amplitude and frequency. Pitch of sound is comparable with the range of colours in a colour spectrum or rainbow.

(c) Balance

The *membranous labyrinth* of the inner ear is concerned with maintaining *balance* in sensing changes arising from different *head* movements (Fig. 13.12).

(i) *Turning or rotational head movements*

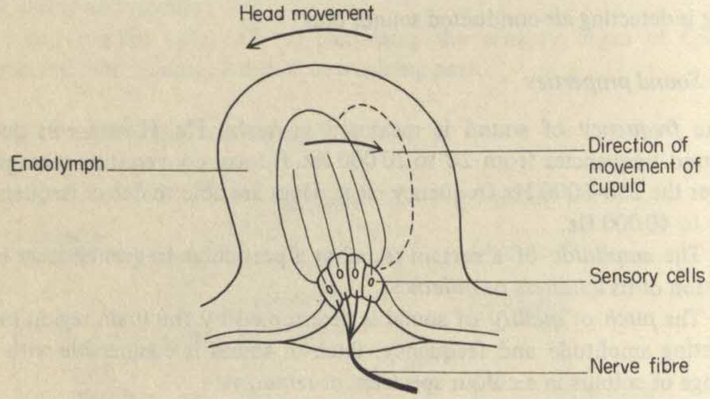
The three semicircular canals are arranged three-dimensionally. Movement of the internal endolymph is detected by sensory cells located in the *ampullae* called *cristae*; these are activated by swinging gelatinous *plates* called *cupulae.* The *rate* of change in position of a turning head is relayed to the brain from the cristae.

(ii) *Tilting head movements*

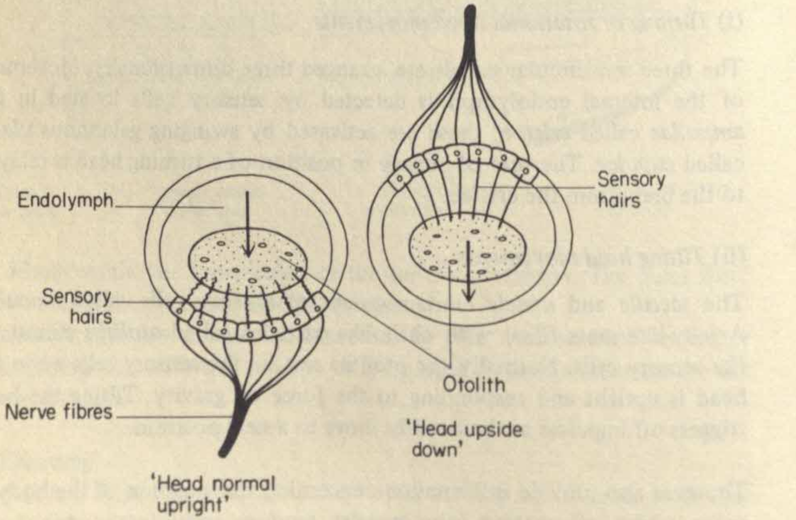
The *saccule* and *utricle* contain groups of sensory cells called *maculae.* A jelly-like mass filled with chalk-like particles called *otoliths* stimulates the sensory cells. Normally the otoliths rest on the sensory cells when the head is upright and responding to the force of gravity. Tilting the head triggers off impulses as the otoliths move to a new position.

The *eyes* also provide information concerning the position of the body in space, whilst information from *muscles, tendons* and *joints* contributes to the body *posture* (Section 14.7).

fig 13.12 ***sensory organs of balance of the inner ear: (a) ampullae and (b) saccule***



(a) Ampulla crista



(b) Otoliths of saccule/utricle

(d) Ear protection and care

(i) *Loud intensity* noise (e.g. in a 'disco') can lead to hearing impairment through damage of the organ of Corti in the inner ear.

(ii) Ears have *few natural protective devices* in controlling sound reaching the inner ear, apart from small muscles connected to the ear ossicles.

(iii) *Muffs* and *earplugs* provide valuable protection in noisy workshops and when using noisy machines.

13.7 HUMAN SKIN

Skin (see Section 12.9) has different *sensory nerve* endings. Those that are located in the epidermis as *free nerve* endings sense temperature changes by *thermoreceptors* which are important in body temperature homeostasis. They are also believed to sense *pain* and light *touch*.

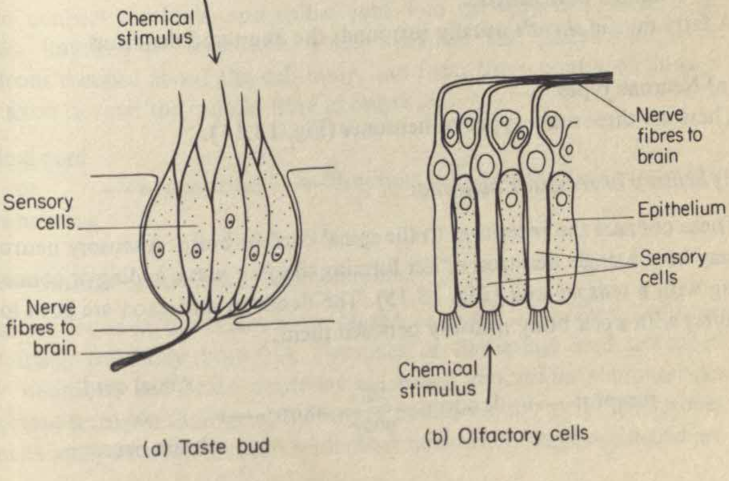
The dermis layer contains the sensory nerve endings that sense *pressure* changes by the *Pacinian corpuscles*. Others, as *nerve plexuses* or networks around hair papillae, detect hair movements.

13.8 HUMAN NOSE AND TONGUE

(a) Tongue

Sensory cells, called *gustatory cells*, are grouped together in *taste buds* located in grooves in the tongue mucous membrane (Fig. 13.13a).

fig 13.13 *sensory cells of (a) the tongue and (b) the nose*



(a) Taste bud

(b) Olfactory cells

Sweetness is detected by taste buds at the tongue tip, *sourness* of acids at the tongue sides, and *bitterness* of alkalis at the tongue back. *Saltiness* can be tasted all over the tongue.

(b) Nose

Sensory cells, sensing smell, are grouped together as an *olfactory patch* on the mucous membrane lining part of the nasal cavity (Fig. 13.13b). The *olfactory* sensory cells may have minute hairs to receive the stimulus.

13.9 INSECT SENSORY ORGANS

Antennae are paired appendages on the head, consisting of long slender jointed organs able to sense *smell, touch* and low-frequency sound.

Cuticle or skin of insects has numerous fine *bristles*, connected to sensory cells which receive touch stimuli. These bristles are found all over the body, particularly on the legs, thorax and antennae.

Mouthparts and forelegs have sensory cells able to distinguish sweet, sour, bitter and salt in tasting food materials. The housefly is observed to use its forelegs in food tasting.

13.10 NEURONES

A neurone consists of three main parts:

(i) the *cell body*, containing a *nucleus* and many energy-providing mitochondria and protein-making ribosomes;
(ii) one *axon*, leading the nervous impulse *away* from the cell body;
(iii) one or more *dendrons*, leading the impulse *towards* the cell body from a number of *dendrites*.

A fatty myelin *sheath* usually surrounds the axon and dendrons.

(a) Neurone types

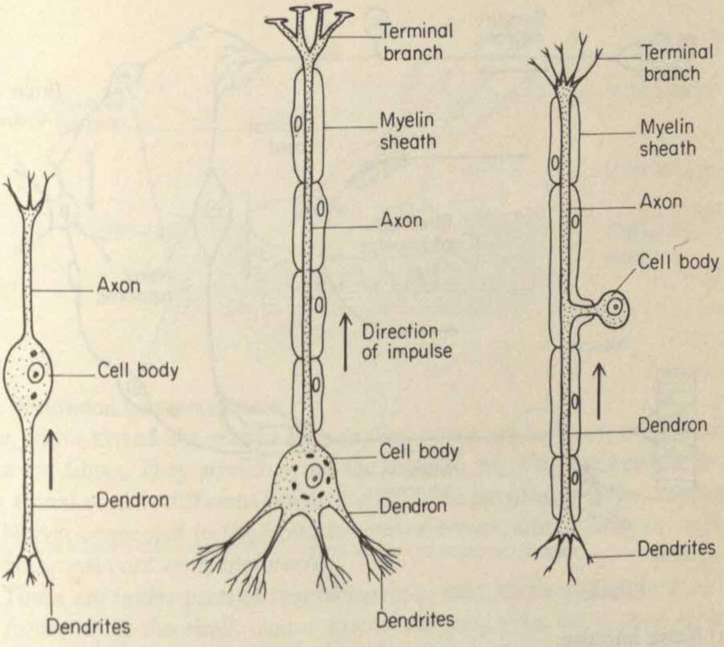
There are three main types of neurones (Fig. 13.14).

(i) Sensory or receptor neurones

These connect the *receptors* to the spinal cord or brain. A sensory neurone may have a single dendron either forming the *free nerve* ending or connecting with a *sensory cell* (Fig. 13.15). The dendron and axon are both long fibres with a cell body midway between them.

$$\text{receptor} \longrightarrow \text{dendron} \xrightarrow[\text{body}]{\text{cell}} \text{axon} \longrightarrow \begin{array}{c}\text{spinal cord}\\ \text{or}\\ \text{brain neurone}\end{array}$$

fig 13.14 *three different kinds of neurones or nerve cells found in mammals*



(a) Bipolar neurone (b) Motor neurone (c) Sensory cell

(ii) *Motor or effector neurones*

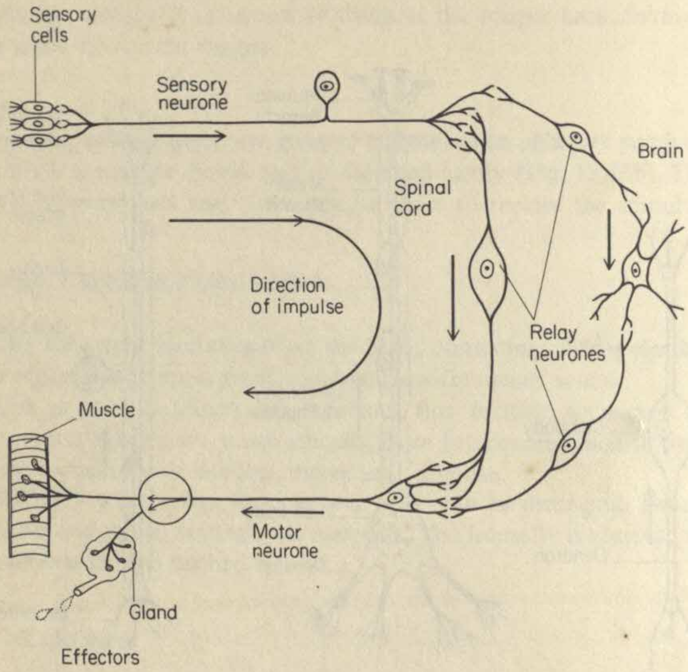
These connect the brain and spinal cord with the *effectors*, muscles or glands. Impulses are collected by the dendrites and passed into *short* dendrons grouped about the cell body, and from there continued down a *long* axon to enter the muscle fibre as *endplates.*

$$\begin{array}{l}\text{spinal cord}\\ \qquad\text{or}\\ \text{brain neurone}\end{array} \longrightarrow \text{dendrites} \longrightarrow \text{dendrons} \xrightarrow[\text{body}]{\text{cell}} \text{axon} \longrightarrow \text{effectors}$$

(iii) *Intermediate neurones or interneurones*

These are found *in* the brain, sense organs, or spinal cord. These neurones have many cell body branches. Neurones in the spinal cord are called *relay* neurones, and brain neurones are called *pyramidal* neurones. An important feature is their great number of dendrites, allowing the neurones to make many *interconnections* with other spinal cord and brain neurones.

fig 13.15 *the arrangement of nerve cells in a reflex arc*



(b) Nerve impulse

Neurones are able to transmit an *impulse*; this is transmitted *electrochemically.* It is *not* a flow of electrons as in an electric current flowing through a copper wire. The impulse is generated by the alternate *inflow* of *sodium* ions into the nerve fibre, and *outflow* of *potassium* ions. The impulse is conducted very rapidly at a speed of 120 m/s.

(c) Synapses

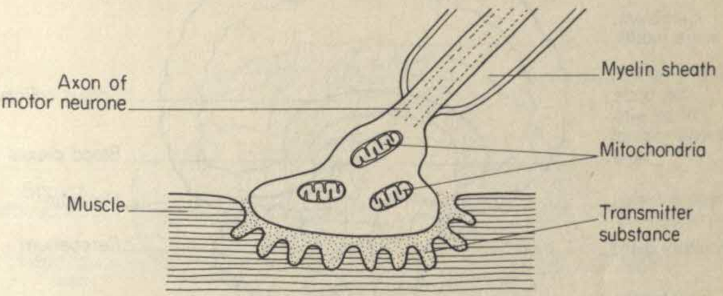
Neurones conduct their impulses into neighbouring neurones across the *gap* between the terminal branch of a neurone and the *dendrite* of another neurone or effector membrane. This point is called the *synapse* (Fig. 13.16).

$$\text{axon} \longrightarrow \text{synapse} \longrightarrow \text{dendrite}$$

$$\text{axon} \longrightarrow \text{synapse} \longrightarrow \begin{array}{l}\text{effector}\\\text{membrane}\end{array}$$

When the impulse reaches the synapse, it releases a *chemical transmitter* which crosses the gap by diffusion and enters the other neurone or effector. Certain drugs, *curare* and organophosphorus *insecticides*, can block the gap and act as nerve poisons, to cause muscle paralysis.

fig 13.16 *a synapse at the end of a motor neurone connecting with a muscle*



(d) Peripheral nervous system

The white thread-like *nerves* seen in dissections are composed of *bundles* of axon fibres. They stretch from the brain to parts of the head, or from the spinal cord to different limbs, and form the *peripheral nervous system.*

Nerves connected to the brain are *cranial nerves*, whilst those connected to the spinal cord are *spinal nerves.*

There are *twelve* pairs of cranial nerves in man; these emerge from holes or *foramina* in the skull. Some supply the ears, eyes, nose, jaws, mouth and face, and others supply the neck, heart, stomach and intestines.

The *thirty-one* pairs of spinal nerves emerge from between the vertebrae, to supply the arms, legs, trunk muscles, diaphragm and the skin.

The *involuntary* or *autonomic* system is the nervous system controlling smooth, involuntary muscle and glands.

13.11 NERVOUS COORDINATION – THE CENTRAL NERVOUS SYSTEM

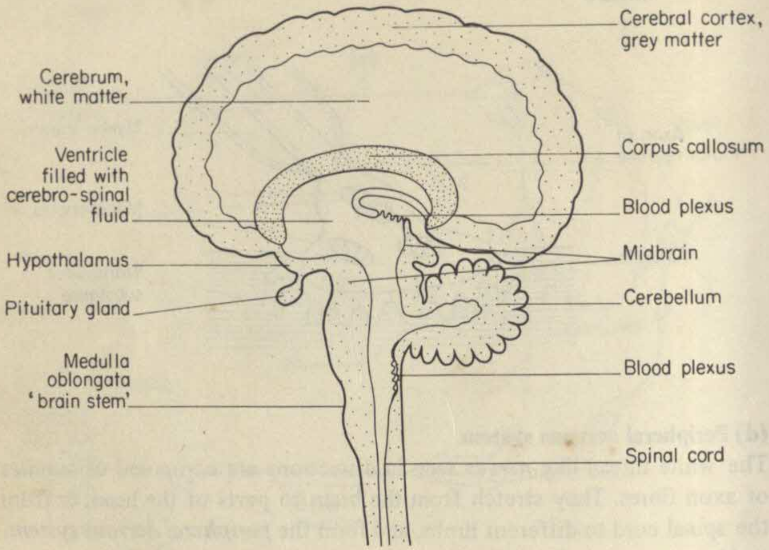
The *central nervous system*, or CNS, in vertebrates is composed of the *brain* and *spinal cord.*

(a) The brain of man

The human brain weighs about 1.5 kg, or 2% of the total body weight. Lower vertebrates, fish, amphibia and reptiles show a division of the brain into forebrain, midbrain and hindbrain; these divisions are not easily seen in birds and mammals.

The following main parts are recognised in the human brain: *cerebrum, cerebellum, medulla* and *thalamus* (Fig. 13.17).

fig 13.17 *a vertical section of the human brain*



(i) *Cerebrum*

Two *cerebral hemispheres* connected with each other by a nerve *tract* form most of the human brain. The outer 3 cm of the cerebrum consists of neurone cell bodies forming the *grey matter* or *cortex*. The neurones are of the intermediate type with dendrites making thousands of interconnections with other neurones.

The surface of the cerebral hemispheres is greatly folded, thus increasing the *surface area* and allowing more neurones to fill the grey matter.

Inside the cerebral hemispheres is the *white matter*, composed of neurone axon fibres. The internal fluid-filled spaces are called *ventricles*, the cerebrospinal fluid being produced by blood *plexuses*.

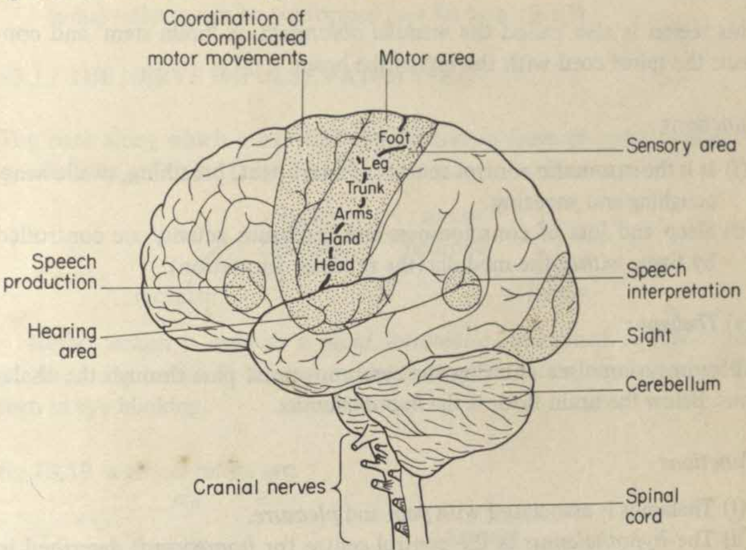
Functions

The brain cerebral hemisphere surface is insensitive to pain. The functions of different *areas* have been determined by the effect of accidental injury, disease or by electrical stimulation. Wilder Penfield (born 1891), a brain surgeon, mapped out the functions of the brain cortex from his findings after performing many brain operations.

(i) *Sensory areas* (Fig. 13.18) receive the impulses from the *receptors* in the skin, eyes, nose and ears.

(ii) *Motor areas* (Fig. 13.18) transmit impulses to the *effectors* in skeletal muscles, speech or glands.

fig 13.18 *the brain sensory, motor and association areas*



(iii) *Association areas* (Fig. 13.18) sort out, interpret and decide action. It is the area where sensory impulses from the eye are made into a *picture*, and where sensory impulses from the ears are *understood.* This area is concerned with *learning, memory, personality*, morals and ethics.

The outermost coverings of the brain are called the *meninges*, and they provide protection and a continuous supply of glucose and oxygen. If deprived of these materials for 2 min, it will lead to irreparable *brain damage.*

Continuous electrical activity, detectable by a recording instrument called the *electroencephalograph*, shows that the brain never rests even when the body is asleep or unconscious.

(ii) *Cerebellum*

This is similar to the cerebrum in having a folded surface to increase its grey matter.

Functions

It *coordinates* voluntary skeletal muscle activity in allowing a person to make accurate and smooth muscle action in walking, etc. It is linked to the cerebrum which starts muscle activity through its motor areas.

Damage to the cerebellum causes a staggering uncoordinated way of walking.

(iii) *Medulla*

This region is also called the ***medulla oblongata*** or 'brain stem' and connects the spinal cord with the rest of the brain.

Functions

(i) It is the *automatic* control centre for heart beat, breathing, swallowing, coughing and sneezing.
(ii) Sleep and loss of consciousness and cerebrum activity are controlled by tissue *within* the medulla (the reticular formation).

(iv) *Thalamus*

All sensory impulses entering the cerebrum must pass through the thalamus. Below the brain floor is the *hypothalamus.*

Functions

(i) Thalamus is associated with *pain* and *pleasure.*
(ii) The *hypothalamus* is the control centre for *homeostasis* described in Chapter 12.
(iii) The region is also a control centre for the *endocrine system*, by the *pituitary gland.*

(b) Spinal cord

The spinal cord extends from the medulla or brain stem to a point near the 'tail'. It is surrounded and protected by meninges and *vertebrae.*

It is a hollow tube, continuous with the brain ventricles, containing *cerebrospinal fluid*. This is a clear fluid having a similar composition to *tissue fluid* (Section 12.1).

The grey matter of the spinal cord is located inside, whilst the white matter of axon fibres is outside the spinal cord, beneath protective meninges.

The spinal nerves are mixed nerves which have two *roots*; the dorsal root is connected with the *sensory* neurone, whilst the ventral root connects with the *motor* neurone. The position of the sensory neurone *cell body* is indicated in the dorsal root *ganglion.*

Functions

(i) It *transmits* sensory and motor impulses to and from the receptors and effectors, or relays sensory and motor impulses to and from the brain.

(ii) Simple *coordination* for certain involuntary automatic actions called spinal reflexes can be performed (see Section 13.12).

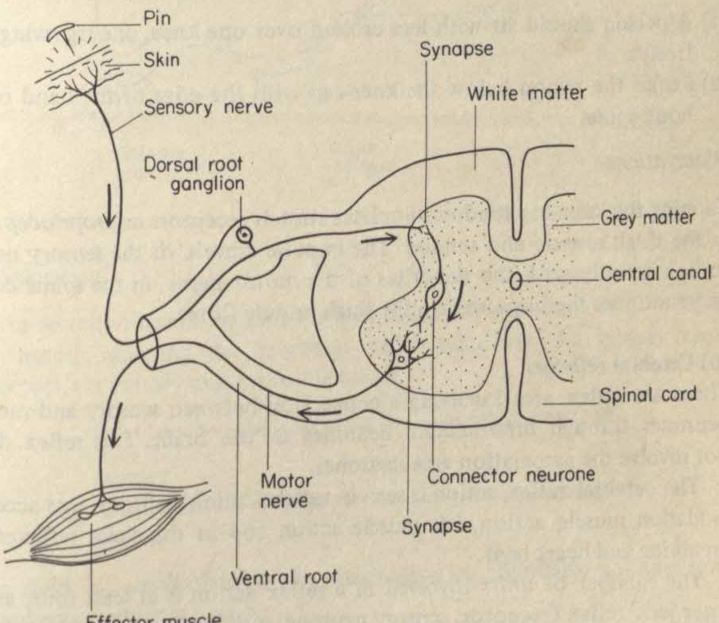
13.12 THE NERVE IMPULSE PATHWAYS

The path along which a nervous impulse travels from receptor to effector is called the *reflex arc* (Fig. 13.19).

receptor → sensory neurone → motor neurone → effector

Reflex action is seen as a *rapid, automatic*, unlearned or inborn response to a stimulus. It is a *protective* instinctive action and an example is seen in eye blinking.

fig 13.19 *a simple reflex arc*



(a) Spinal reflexes

These are reflex arcs involving connection between sensory and motor neurones either by a synapse in the spinal cord or through an *intermediate* neurone.

This reflex action is seen in the 'knee jerk' or hand withdrawal from a hot surface.

Knee jerk reflex

receptor → sensory neurone
effector ← motor neurone ←

Hand from heat reflex

receptor → sensory neurone → intermediate neurone
effector ← motor neurone ←

Experiment 13.2 *the knee jerk reflex*

Procedure

(i) A person should sit with legs crossed over one knee, one leg swinging freely.
(ii) Strike the region below the knee-cap with the edge of the hand or a book spine.

Observations

Tapping the knee-cap tendon stimulates stretch receptors or *proprioceptors* in the thigh muscle and tendon. The impulse travels via the *sensory* nerve to link directly with the dendrites of the *motor* nerve, in the spinal cord, and continues the impulse into the thigh muscle fibres.

(b) Cerebral reflexes

These are reflex arcs involving a connection between sensory and motor neurones through *intermediate* neurones in the brain. This reflex does *not* involve the association area neurones.

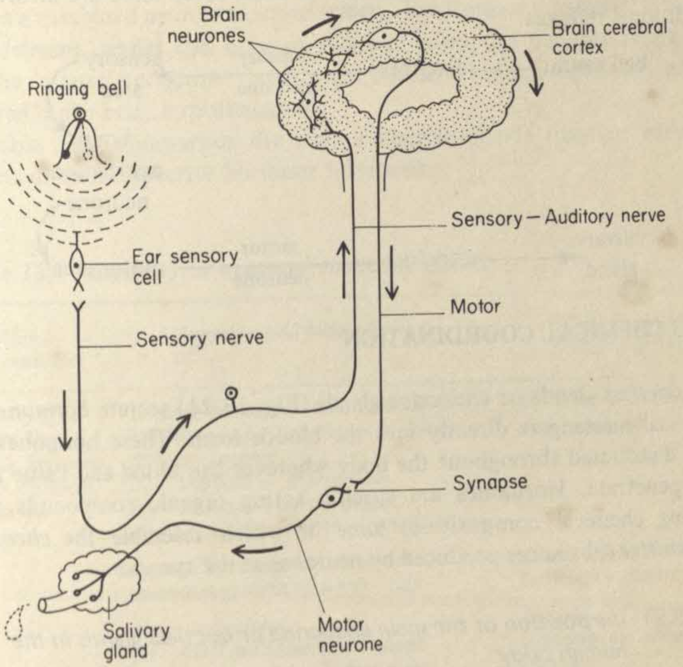
The cerebral reflex action is seen in various 'blink' reflexes, lens accommodation muscle action, iris muscle action and in the major reflexes of breathing and heart beat.

The number of *units* involved in a reflex action is at least four, as in 'knee jerk' reflex (receptor, sensory neurone, motor neurone and effector). In others it may number five with the additional *intermediate* neurone.

Conditioned or learned reflexes

When a nerve impulse travels in a reflex arc which involves brain *association neurones* to *decide* on what response is to be made to the original stimulus, the response is called a *conditioned reflex* (Fig. 13.20).

fig 13.20 *a conditioned reflex arc*



(i) *Salivation*

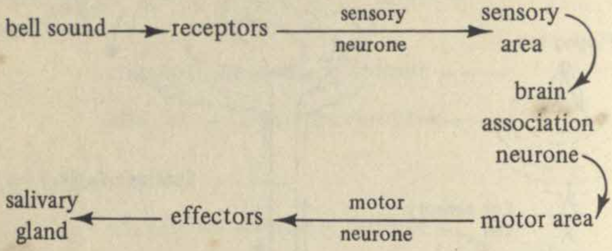
Saliva secretion occurs by *simple reflex* caused by the touch of food inside the mouth affecting the receptors which stimulate the salivary gland effectors, via sensory and motor neurones.

food touch → receptors → sensory neurone ↘
salivary glands secrete ← effectors ← motor neurones ↙

The *sight* and *smell* of food can cause salivation. Similarly a dinner gong sound can produce salivation.

Ivan Pavlov (1849–1936), a physiologist, carried out experiments by making dogs salivate at the sound of a ringing bell, which the dogs had *learnt* to associate with feeding times. The dogs were *conditioned* to associate the appearance of food with the bell ringing; they learnt from information *stored* in the cerebrum, to salivate on hearing the bell even if no food appeared.

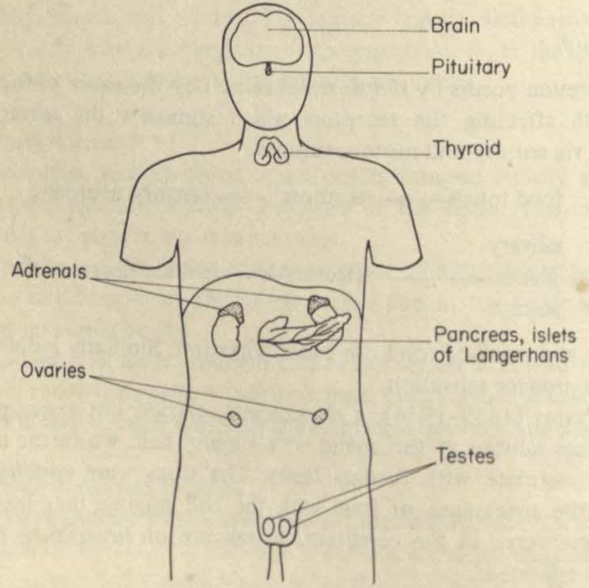
Such conditioned reflexes are an important part of *learning* in vertebrate and some invertebrate animals. At least seven *units* are involved in conditional reflexes.



13.13 CHEMICAL COORDINATION

The *ductless* glands or *endocrine* glands (Fig. 13.21) secrete *hormones* or chemical messengers directly into the bloodstream. These hormones are then distributed throughout the body wherever the blood and tissue fluid can penetrate. Hormones are specific acting organic compounds with varying chemical composition, some of which resemble the *chemical transmitter* substances produced by neurones at the synapse.

fig 13.21 *the position of the main endocrine or ductless glands in the human body*



Hormones are therefore an additional means of coordination and communication. Together with the nervous system, the endocrine system forms a combined *neuroendocrine system*. The hormone pathway is by the *bloodstream*, whilst the nervous pathway is by the neurone reflex arc.

The 'master' endocrine gland in the human body is the *pituitary gland*, located in the brain hypothalamus.

Table 13.1 summarises the main endocrine glands together with the effects of their respective hormone secretions.

Table 13.1 *summary of mammal endocrine glands*

Gland (and position)	*Hormone and main effects*	*Deficiency and excess effects*
Pituitary (below the brain). Secretes many different hormones	*Trophic hormones*: stimulate the following endocrine glands to release their hormones: (a) Thyroid – *thyrotropin* (b) Adrenal – *corticotropin* (c) Ovaries and testes – *gonadotropins*	Disorders of normal gland function
	Growth hormone: *somatotropin* promotes growth of *whole* body	Excess: gigantism Deficiency: dwarfism
	Neurosecretions: (a) *ADH, antidiuretic hormone* (*vasopressin*) – kidney water reabsorption (b) *Oxytocin* – uterus contraction *Prolactin* – milk secretion (see Table 15.5)	Disorders of normal function, e.g. water diabetes
Thyroid (near larynx)	*Thyroxine*: (a) Controls body metabolism, energy release in mitochondria (b) Influences growth (tadpole metamorphosis)	Deficiency: cretinism in children Deficiency: in adults, slowing down metabolism; sluggishness Excess: eyeballs protrude; metabolism increased; restlessness
Adrenals (close to kidneys)	*Medulla hormones*: mainly *adrenaline*: (a) Affects *blood circulation* by increased heart beat, blood flow, vasodilation; prepares body for *fight* or *flight* (b) Slows down *kidney* function (c) Increases blood sugar conversion from glycogen	
	Cortex hormones: *Hydrocortisone* in metabolism of lipid, protein and carbohydrates	Deficiency: blood sugar disorders; combats stress

Table 13.1 *cont.*

Gland (and position)	*Hormone and main effects*	*Deficiency and excess effects*
Pancreas (islets of Langerhans)	Mainly *insulin*: controls blood sugar; converts glucose to glycogen *Glucagon*: converts glycogen to glucose	Deficiency: sugar diabetes, increase in blood sugar level Excess: nerve cell starvation and coma
Gonads (male and female reproductive organs)	*Oestrogen* (female ovary): secondary sexual features, pubic hair, mammary gland, and menstrual cycle *Progesterone*: change in uterus after ovulation and in pregnancy (see Table 15.5) *Testosterone* (male testes): secondary sexual features, pubic hair, facial hair, voice change	General: personality and sexual changes, sterility and abortion
Adrenal cortex	Sex hormones producing body changes as for gonads	Excess: sexual desire changes
Digestive tract (a) Stomach	*Gastrin*: stimulates gastric juice secretion	
(b) Intestine wall	*Secretin*: stimulates pancreatic juice flow	

13.14 HOMEOSTASIS IN THE ENDOCRINE AND NERVOUS SYSTEMS

Homeostatic systems depend for their efficient operation in having a *feedback* system, which allows information to pass by negative or positive feedback (see Section 12.1).

In the *endocrine system* the feedback of information is *slow*, because the ductless glands must first release their hormones which travel by the bloodstream to reach the particular organ. It then takes time to restore a specific concentration to the norm, and then excess of the hormone in the blood causes feedback to slow or stop further hormone production. Table 13.2 summarises homeostasis in thyroid gland activity.

In the *nervous system* the feedback of information is very *rapid*; this is because the impulse is conducted electrically through neurones. Impulses from a muscle stretch receptor are rapidly transmitted to the brain, informing it of change in tension. The adjustment does not 'waver' about a norm as in metabolism homeostasis.

Table 13.3 compares nervous and endocrine communication.

Table 13.2 *homeostasis in thyroid gland activity*

	Excess thyroid secretion	*Deficient thyroid secretion*
Norm (set point)	Thyroxine in blood *rises* to over 6.0 μg/100 cm^3. Body metabolism *increases*	Thyroxine in blood *falls* to below 3.0 μg/100 cm^3. Body metabolism *slows down*
Sensory detectors	Detectors located in the pituitary gland detect thyroxine changes	
Corrective mechanism	Pituitary gland produces *less* thyrotropin, causing thyroid gland to *reduce* thyroxine secretion	Pituitary gland produces *more* thyrotropin, causing thyroid gland to *increase* thyroxine secretion
Negative feedback restores norm	Thyroxine blood level restored to 3–6 μg/100 cm^3. Body metabolism normal	Thyroxine blood level restored to 3–6 μg/100 cm^3. Body metabolism normal
Positive feedback effects	Thyroxine secretion continues to *increase* above norm (6.0 μg/100 cm^3) causing goitre (hyperthyroidism), physical/mental restlessness, thyroid gland enlargement	Thyroxine secretion continues to *fall* below norm (3.0 μg/100 cm^3) causing cretinism (hypothyroidism), physical/mental sluggishness

Table 13.3 *comparison of nervous and endocrine communication*

	Nervous communication	*Endocrine communication*
1	Response to a stimulus, internal or external	Response to a stimulus, internal or external
2	Nervous response *more rapid*	Hormonal response *slower*
3	Impulse travels *electrochemically* along *axons* and *chemically* across *synapses* as transmitter substances, e.g. acetylcholine.	Impulse travels *chemically* as *hormones* in *blood*
4	Response is *specific* in certain muscle or gland	Response is *widespread* over the body
5	Response is *short-lived* in reflex muscle contraction	Response is *long-lasting* in growth or metabolism
6	Does not influence specific chemical changes	Influences specific chemical changes and regulates metabolism, growth and reproduction

13.15 PLANT RESPONSES

Plants, apart from unicellular motile algae, e.g. *Chlamydomonas*, respond to affecting stimuli in a different manner from animals.

The main coordination system in flowering plants is the chemical transmitter substance, the plant hormones (see Sections 11.9 and 11.10).

Table 13.4 compares plant and animal irritability.

Table 13.4 *differences in multicellular plant and animal irritability*

	Multicellular plants	*Multicellular animals*
1	Respond to similar stimuli except *sound*	Respond to *all* stimuli including sound
2	No nervous system	Nervous system present
3	Stimuli received in definite *regions* – stem and root tip	Stimuli received by *sensory* cells and organs
4	Stimulus must be *long-lasting*	Stimulus need only be *brief*
5	Stimulus transmitted *chemically* – plant hormones	Stimulus transmitted *chemically* – animal hormones – *and electrochemically* in nerve cells
6	Stimulus travels by *translocation*	Stimulus travels along *nervous pathways* – reflex arc
7	Response is *slow* in tropic response	Response *rapid* in reflex action
8	Response results in *growth* movement	Response results in *locomotion* or *movement*
9	Causes a definite long-lasting effect – elongation or bending	Causes short-duration effect

13.16 QUESTIONS

1 Draw a labelled diagram showing the external appearance of the human brain. Give the functions of *four* parts. Draw and describe how a *named* reflex response is brought about.

2 Describe the structure of a mammal ear. Outline the functions of the outer, inner and middle ear regions.

3 Compare and contrast hormonal and nervous controls. Describe one method of homeostasis by means of hormones.

4 Draw and label diagrams to show how the normal mammal eye is able to respond to changes in (a) light intensity, (b) the distance of an object from the eye.

5 What is a nerve impulse? How does it cross to other neurones or effectors? What is a reflex arc?

4
5
6

CHAPTER 14

SUPPORT AND MOVEMENT

14.1 PHYSICAL PRINCIPLES

(a) Density

The amount of matter or mass in a certain unit volume is the *density* of the body. Earth has a density of 5500 kg/m^3, water 1000 kg/m^3, and air 1 kg/m^3.

(b) Forces

A resting or non-living organism will remain inert in one position unless pushed or pulled by external forces.

A force is the means to cause *movement* by a *thrust*, a push, or *tension*, a pull.

(c) Machines

These are devices by which a force called the *effort* is applied at one point to overcome a force or *load* at another point.

The *lever* is the main type of machine in animal bodies. It consists of a rigid bar turning at a *pivot*.

(d) Friction

A force which *slows down* or prevents movement is called *friction*. Friction occurs between the foot and ground, food bolus and oesophagus, lungs and ribcage, and between bones in joints. *Lubrication* will overcome friction.

(e) Buoyancy

This is the *upthrust* or force supporting a body in air or water; it is equal to the *weight* of water or air that the body displaces. A floating body 'appears' to *lose* weight. A human body with lungs *inflated* floats since it displaces more water than a body with *deflated* lungs, which sinks.

(f) Stability

A body has a *centre of gravity*, a central point through which the *whole weight* of the body is considered to act.

A human body standing upright is *stable* with its centre of gravity *inside* the body.

A person standing on one leg is *unstable* and liable to topple over because the centre of gravity has moved *outside* the body.

Stability is important in a body at rest or in motion.

14.2 HYDROSTATIC SKELETONS AND EXOSKELETONS

Animals have *skeletons* of three main types: hydrostatic skeletons, exoskeletons and endoskeletons (Section 14.3).

(a) Hydrostatic skeletons

Soft-bodied animals such as *Amoeba*, *Hydra*, jelly-fish and earthworm are without *hard* tissues which support their bodies. Their bodies have *rigidity* due to osmotic pressure exerted by liquid, mainly water, within the cell cytoplasm or body cavity, acting upon a stiff or elastic plasma membrane or muscle tissue.

(i) *Amoeba*

The outer plasma membrane is of a gel-like consistency in the *ectoplasm* and withstands the pressure of the fluid *endoplasm*. The *gel* cytoplasm can change into the liquid *sol* cytoplasm, thus allowing *Amoeba* to change its body shape.

(ii) *Hydra*

This multicellular organism has a body supported partly by *musculo-epithelial* cells in the ectoderm and endoderm. These cells have *muscle tails*. Contraction of the muscle tails occurs by a stimulus from the nerve net. This causes the cells to *decrease* in volume. Relaxation of muscle tails causes the cells to *increase* in volume.

When endoderm muscle tails contract, the body lengthens. Body shortening occurs when ectoderm muscle tails contract and endoderm cells relax. The ectoderm and endoderm musculoepithelial cells act *oppositely* to each other. This is called *antagonistic action*.

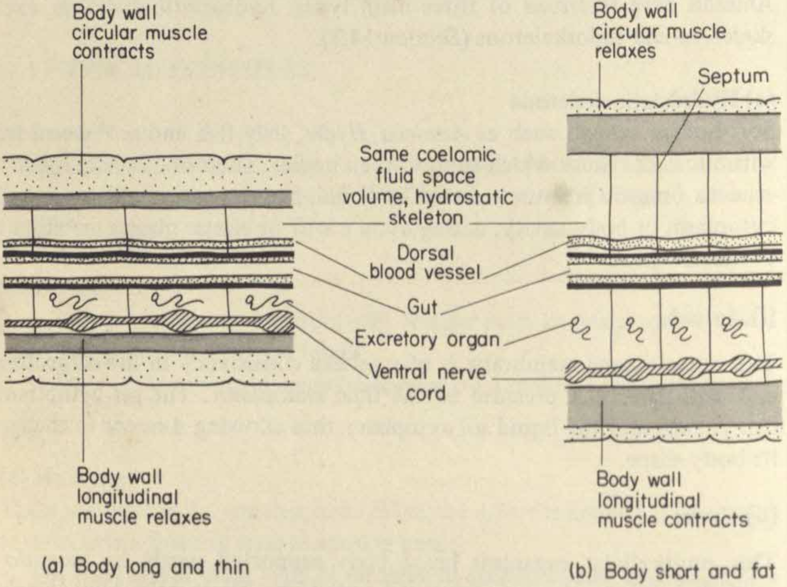
(iii) *Earthworm*

Two layers of *muscle tissue* are arranged at right-angles to each other in the earthworm body wall. One is the outer *circular muscle* layer beneath the epidermis, the other is the inner *longitudinal* muscle layer.

Coelomic fluid fills the space between the gut and body wall in each segment cavity. The fluid in each segment has a *constant* volume.

Change in body shape is by means of the body wall muscles. *Relaxation* of the longitudinal muscle and circular muscle *contraction* makes the body long and thin. Longitudinal muscle *contraction* and circular muscle *relaxation* makes the body short and fat. This antagonistic action is shown in Fig. 14.1.

fig 14.1 *antagonistic muscle action in earthworm,* Lumbricus *sp., body movement*



Body wall circular muscle contracts
Body wall circular muscle relaxes
Septum
Same coelomic fluid space volume, hydrostatic skeleton
Dorsal blood vessel
Gut
Excretory organ
Ventral nerve cord
Body wall longitudinal muscle relaxes
Body wall longitudinal muscle contracts

(a) Body long and thin (b) Body short and fat

The coelomic fluid volume remains *constant* and fills the *changing* shape in the coelomic cavities. The coelomic fluid exerts hydrostatic pressure in response to changes in surrounding pressure exerted by the gut and body wall.

(b) Exoskeletons

Arthropods, such as the cockroach and crab, produce a hard outer *cuticle* layer from the epidermis which forms the outer *exoskeleton*.

Molluscs, oysters and snails *continually* produce an exoskeleton in the form of a hard outer shell.

Certain vertebrates may have an exoskeleton as *scales* in fish, or *plates* and *shields* seen in reptiles and in particular the tortoise.

14.3 ENDOSKELETONS

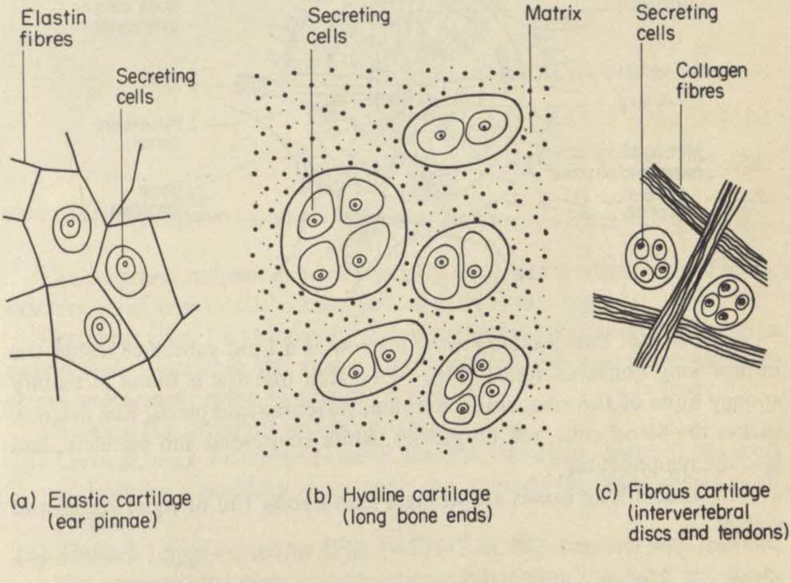
The vertebrate animals have an *internal* endoskeleton mainly composed of *bones*.

(i) *Cartilage*

Cartilage forms the entire skeleton of cartilaginous fish, e.g. shark and dogfish, and also most of the skeleton in *embryo* vertebrates.

Cartilage tissue (Fig. 14.2) is pliable, consisting of cells in *lacunae* surrounded by a groundwork or matrix material.

fig 14.2 *different types of cartilage tissue*



(a) Elastic cartilage (ear pinnae)

(b) Hyaline cartilage (long bone ends)

(c) Fibrous cartilage (intervertebral discs and tendons)

A glass-like cartilage covers the ends of mammal bones as *hyaline* cartilage. The ear pinnae and nose septum consist of *elastic* cartilage. The discs between spinal vertebrae are composed of *fibrous* cartilage. Each type of cartilage has specific physical properties.

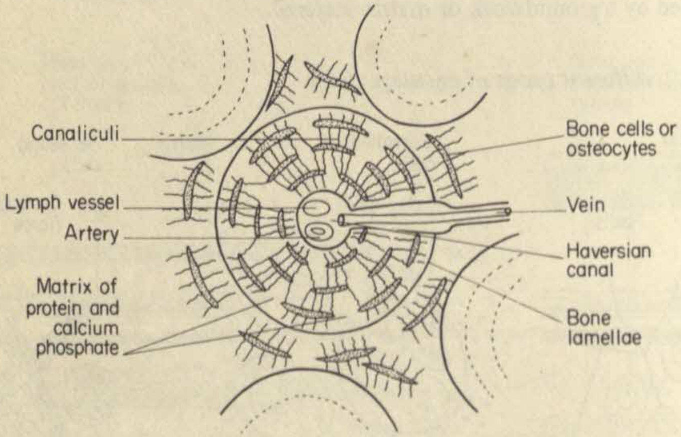
(ii) *Bone*

Bone cells called *osteocytes* are found in spaces or *lacunae*. Each cell has strands of its protoplasm connecting with other bone cells by fine channels or canaliculi. These link up with central *Haversian canals* providing essential food and oxygen.

An intact whole bone consists of 45% water, 30% protein, 15% calcium salts and 10% lipids. The protein in bone is called *collagen* and can produce gelatine. The inorganic salts are mainly calcium phosphate with smaller amounts of magnesium chloride and calcium fluoride.

Bones have a *low density* owing to the following structure: *compact* bone (Fig. 14.3) is the outermost part, with *spongy* bone as an inner layer with larger *lacunae* spaces than in compact bone.

fig 14.3 *structure of compact bone*



Marrow is of two kinds. *Yellow* marrow is a lipid substance inside the hollow *long* bones of limbs (Fig. 14.4). *Red* marrow is found in mainly spongy bone of the ribs, skull, sternum, vertebrae and pelvis. Red marrow makes the *blood* cells, red corpuscles, white corpuscles and platelets, and also the lymphocytes.

The *hollow* long bones are stronger than a *solid* rod of equal length and weight.

(a) Mammal skeleton

A vertebrate skeleton (Plate 14.1) is composed of:

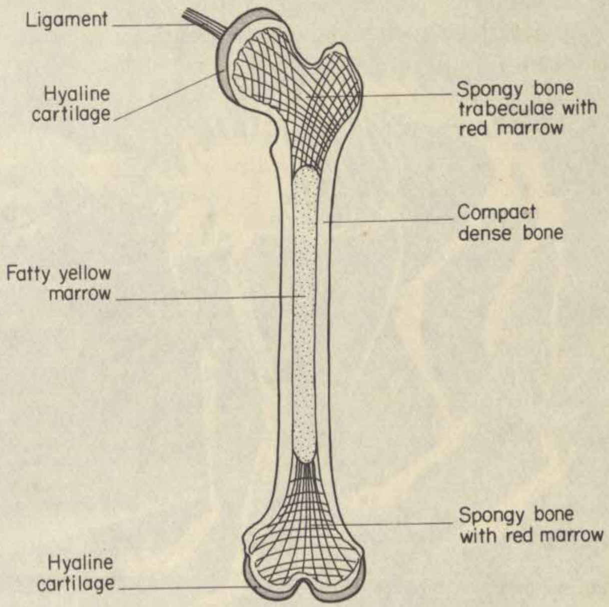
(i) the *axial* or backbone-and-skull skeleton,
(ii) the *appendicular* or limb skeleton.

(i) *Axial skeleton*

This includes the skull, vertebral column and rib cage.

The *skull* consists of the *cranium* surrounding and protecting the brain, with a fixed upper jaw or *maxilla* and movable lower jaw or *mandible*. Skull bones are spongy to reduce the skull density.

fig 14.4 *internal structure of a mammal femur bone seen in longitudinal section*



The *vertebral column* is made up of individual vertebrae separated by *intervertebral* discs or cushioning pads of fibrous cartilage.

Vertebrae (Fig. 14.5) have the following general structure: a *centrum*, a *neural arch* containing the spinal cord, together with two *transverse* processes and a *neural spine* to anchor muscles.

There are *five* different sets of vertebrae.

(i) *Cervical*, neck vertebrae (seven): the first, the *atlas*, supports the skull and allows a nodding movement; the second, the *axis*, allows skull rotation.

(ii) *Thoracic*, chest vertebrae (Fig. 14.5) (12 or 13): connect with ribs and the *sternum*, forming a thoracic cage protecting the heart and lungs and allowing respiratory movements.

(iii) *Lumbar*, waist vertebrae (seven): strongly built.

(iv) *Sacral*, hip vertebrae (five): these are joined together to strengthen the *sacrum*.

(v) *Caudal*, tail vertebrae (variable): the number being dependent on the mammal species.

Vertebrae have an inverted T or sectional structure, comparable to the *T-girder* in building construction. The complete vertebral column is arched in mammals in a manner resembling a *bridge* arch. The limbs can be compared to the bridge *pillar* supports.

plate 14.1 *the skeleton of a cat,* Felis domesticus *(Griffin Biological Laboratories)*

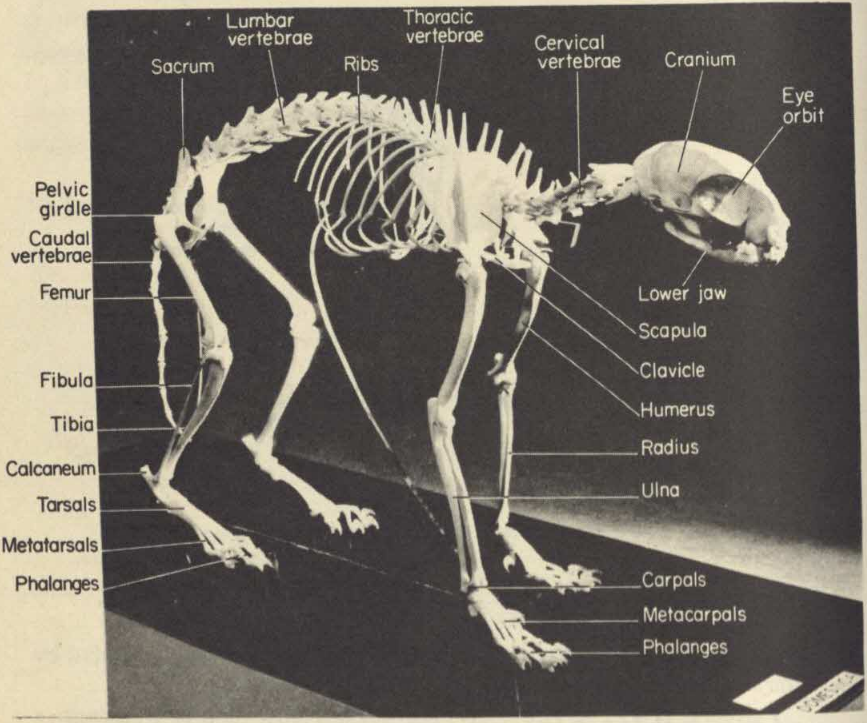
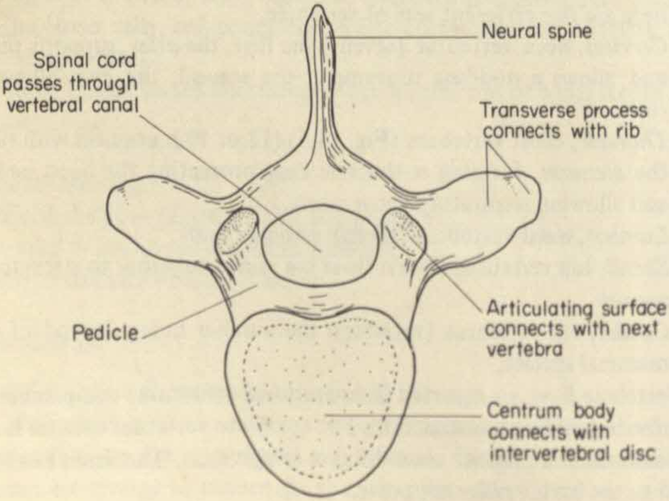


fig 14.5 *structure of a mammal thoracic vertebra*


Neural spine
Spinal cord passes through vertebral canal
Transverse process connects with rib
Articulating surface connects with next vertebra
Pedicle
Centrum body connects with intervertebral disc

Experiment 14.1 *to compare an arch and beam in support*

Procedure

(i) Cut strips of cardboard 3 cm by 15 cm. Place one strip as a beam supported across two books spaced at 10 cm apart.
(ii) Arch the other strip between books spaced at 10 cm apart
(iii) Carefully load 2 pence coins onto the beam card until it collapses and repeat the procedure with the arched card.

Observation

The arch supports more weight than the beam. Arching strengthens and provides a lighter supporting structure than a similar straight beam of equal weight.

(ii) *Appendicular skeleton*

This consists of two girdles and limbs.

(1) Pectoral girdle

This is made up of a *clavicle* or collar bone and flat *scapula* or shoulder blade. It is attached by muscles and tendons to the thoracic vertebrae. The connection is a *loose* one acting as a *shock absorber* to *dissipate* the upthrust received by the forelimbs as they strike the ground.

(2) Pelvic girdle

This is a strong structure, supporting the abdominal organs, made up of ilium, ischium and pubis bones, and *firmly* connected to the sacrum by strong *ligaments*. Strength is needed to *absorb* the *thrust* transmitted up the legs in walking or running.

(3) Pentadactyl limbs

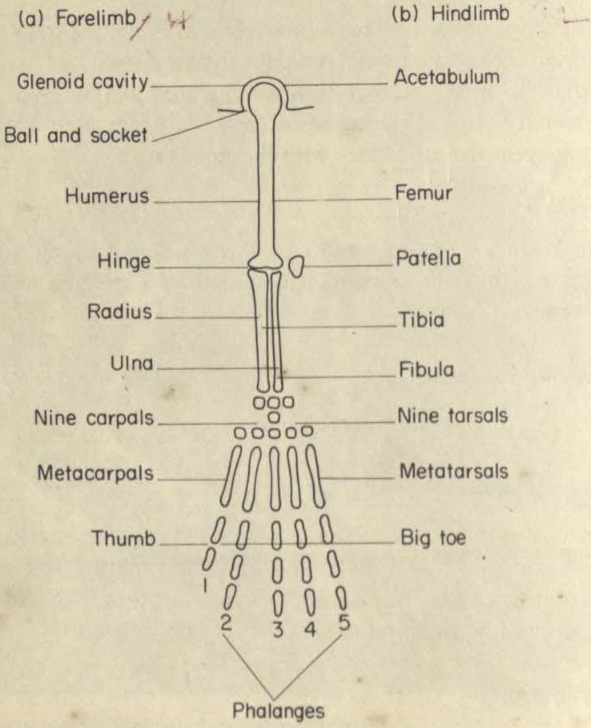
The skeleton structure of the forelimbs and hindlimbs follows a similar general plan seen in the limbs of amphibia, reptiles, birds and mammals. The limbs have *five* (penta) fingers or toes and are *pentadactyl* limbs (Fig. 14.6). There is some variation in the *number* of digits, and terminal bones in different vertebrates.

Joints

A joint is that part of the endoskeleton where *two* or more bones meet. Joints are of three main types (Fig. 14.7):

(i) *Immovable joints* are seen as sutures between the skull bones, and in the pelvic girdle between it and the sacrum.

fig 14.6 *the structure of the vertebrate pentadactyl limb, or limb having five digits*



(ii) *Movable cartilaginous joints* are between the vertebral centra, giving the spinal column flexibility by the intervertebral discs.

(iii) *Movable synovial joints* allow considerable movement, as seen in the jaw, between the atlas and axis, and between bones in the fingers and toes.

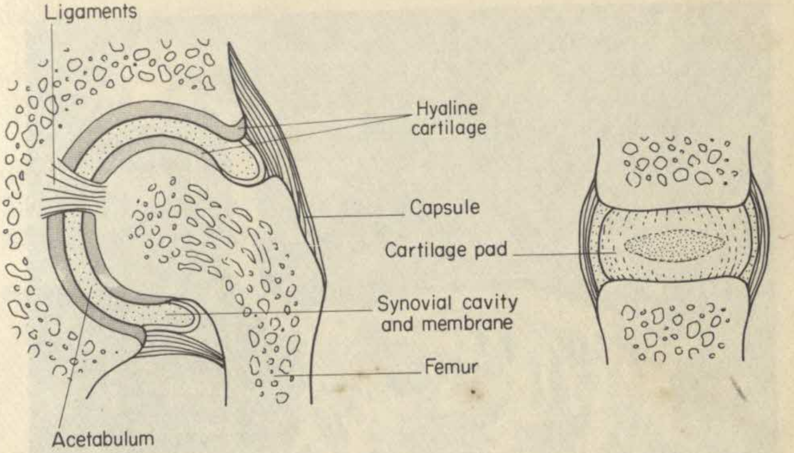
Ball-and-socket joints in the hip and shoulder allow limb movements in many directions.

Hinge joints in the knee and elbow allow limited movement in *one* direction.

Synovial joints have the following general structure. The bone ends are covered in *smooth* hyaline cartilage which is lubricated by the *synovial fluid* which overcomes any friction between solid surfaces in contact with each other. The *lubricant* is secreted by the *synovial membrane* which lines the joint *capsule*.

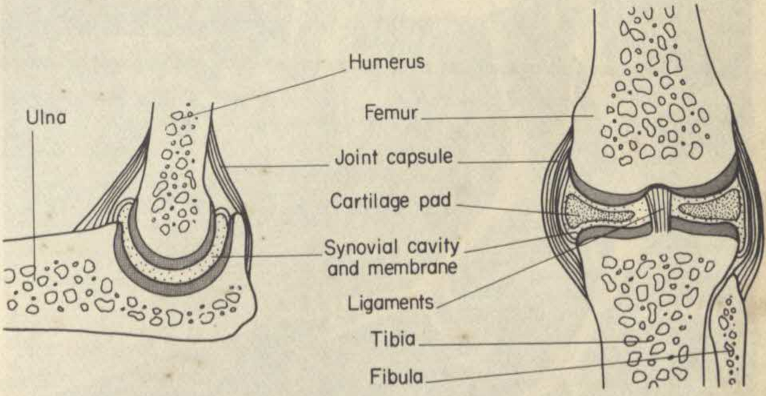
Tough *fibrous capsular tissue* forms the *joint capsule*. Joints are made stronger by *ligaments* which can be part of or separate from the joint capsule.

fig 14.7 *the structure of various movable joints*



(a) Ball and socket (hip)

(b) Gliding joint (vertebrae)



(c) Hinge (elbow)

(d) Hinge (knee)

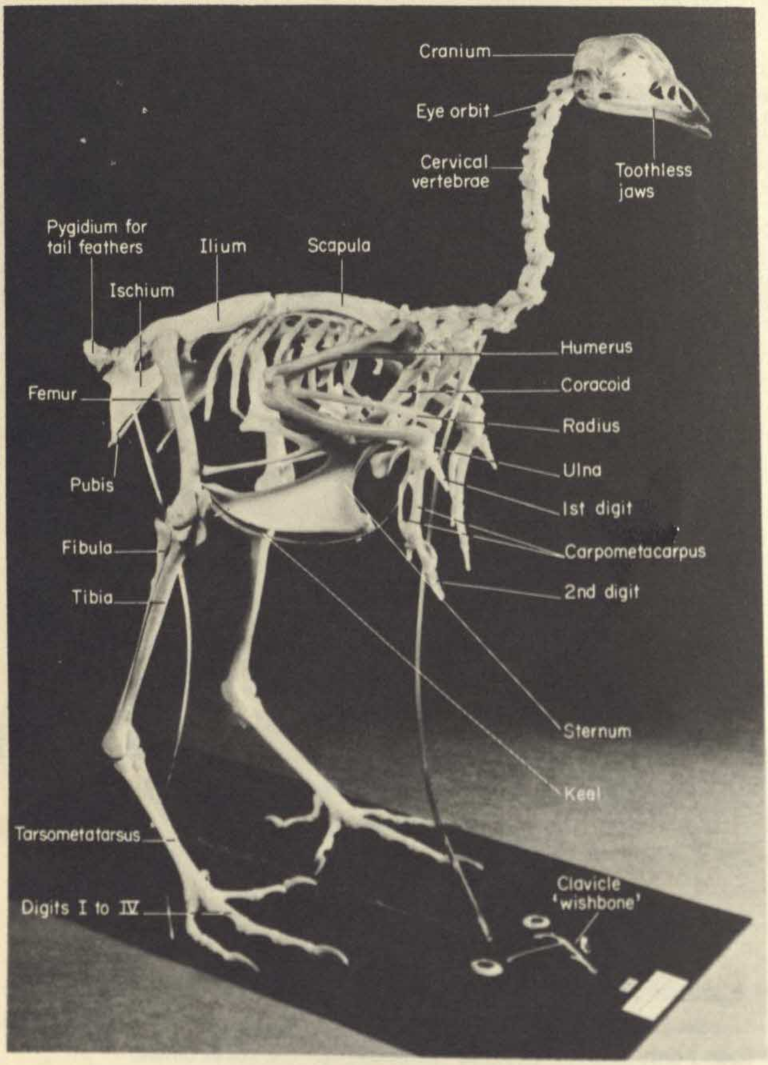
Ligaments are important connective tissues. *Fibrous* ligaments are made of collagen and connect bones together across most joints. *Elastic ligaments* are found only in a few parts of the body, e.g. the vocal cords.

One end of a synovial joint is *concave*, the other is *convex*. The concave part of the hip joint is called the *acetabulum*, whilst the concave part of a shoulder joint is called the glenoid cavity.

(b) Bird skeleton

The following summarises the adaptations of the bird skeleton (Plate 14.2) for flight:

plate 14.2 *the skeleton of a domestic fowl,* Gallus *sp. (Griffin Biological Laboratories)*



The long bones are *hollow* and contain *air sacs* connected to the lungs, making the bird skeleton a *low*-density structure.

The *sternum* has a deep keel to anchor the powerful *pectoralis* flight muscles.

The pectoral girdle is strengthened by a strut-like *coracoid* bone.

Tail or caudal vertebrae are reduced to overcome *drag forces*.

Only *three* digits remain in the pentadactyl wing structure. The *carpo-*

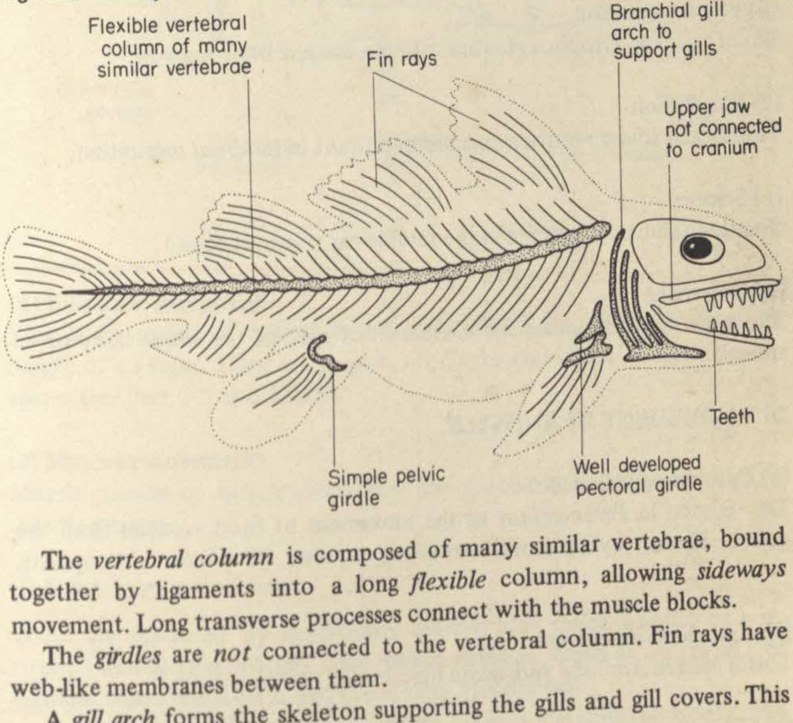
metacarpus bone is an elongated hand bone serving to support the *primary flight* feathers; the *secondary* and *tertiary* flight feathers are connected to the humerus and ulna bones.

The hindlimbs or legs have elongated foot or *tarsometatarsus* bones which keep the flapping wings clear of the ground and help in a fast 'take off'.

(c) Fish skeleton

The fish skeleton (Fig. 14.8) is a *weak* structure compared to other vertebrates, much of its support being provided by the surrounding water.

fig 14.8 *a bony fish endoskeleton*


Flexible vertebral column of many similar vertebrae
Fin rays
Branchial gill arch to support gills
Upper jaw not connected to cranium
Teeth
Simple pelvic girdle
Well developed pectoral girdle

The *vertebral column* is composed of many similar vertebrae, bound together by ligaments into a long *flexible* column, allowing *sideways* movement. Long transverse processes connect with the muscle blocks.

The *girdles* are *not* connected to the vertebral column. Fin rays have web-like membranes between them.

A *gill arch* forms the skeleton supporting the gills and gill covers. This gill arch is used in the respiratory movements.

14.4 FUNCTIONS OF A MAMMAL SKELETON

(a) Support

The soft organs, mainly the muscles, need to be suspended and bones in the skeleton provide attachment points. The vertebral column is the primary means of support in vertebrates.

Limbs act as *props* in raising the body off the ground. A stranded whale is unable to do so, and its internal organs are compressed by the upthrust from the ground acting in response to the unsupported body mass.

(b) Body shape

The *shape* of a human hand or bat's wing is a consequence of skeleton structure.

(c) Protection

Soft organs, such as lungs, heart and brain, are protected from injury by the thoracic cage and skull, respectively.

(d) Blood formation

Blood cells and lymphocytes are made in the *red* bone marrow.

(e) Respiration

Thorax and ribcage *movements* are important in *external* respiration.

(f) Sensory

The three auditory *ossicles* in the middle ear transmit sound.

(g) Movement

The bones provide levers for movement of *part* or the *whole* body of an animal.

14.5 MOVEMENT IN ANIMALS

(a) Cytoplasmic movement

This is seen in *Paramecium* as the movement of food vacuoles from the gullet. Similar cytoplasmic streaming is seen in *Elodea* chloroplasts.

(b) Amoeboid movement

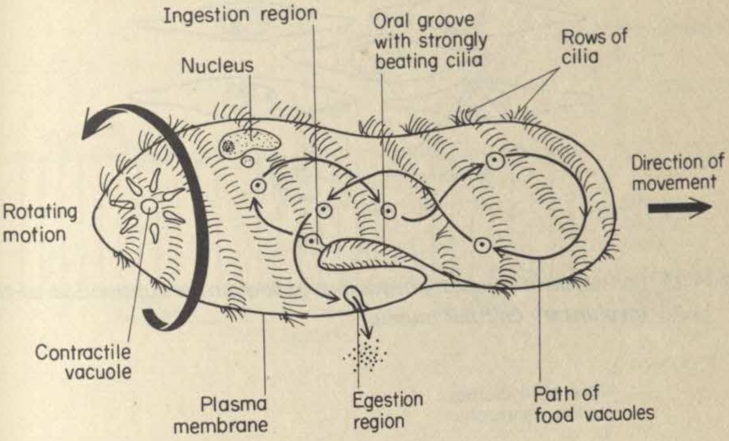
This is seen in *Amoeba* and white blood cells.

(c) Ciliary movement

This is the movement due to the *rhythmic* beating action of *cilia* present in *large* numbers all over the *Paramecium* body surface (Fig. 14.9). Ciliated *epithelium* is found lining the mammal lungs and oviducts; they serve to move fluid and solid particles.

Ciliary movement can therefore be responsible for moving the whole organism, as in the *locomotion* of *Paramecium*, or in *movement* of *small particles* as in the mammal lung (see Fig. 19.10).

fig 14.9 *ciliary movement in a* Paramecium *sp.*



(d) Flagellate movement

This is by means of one or two flagella which are 10 to 20 times the length of a *cilium*. They are seen in the *Hydra* endoderm cells and human sperm (see Figs. 3.5 and 15.20).

(e) Muscular movements

Muscle consists of *muscle cells*; these are *effector* cells composed of *contractile protein*.

(i) *Involuntary movements*

These are produced by involuntary muscle, also called smooth or non-striated muscle (Fig. 14.10). This muscle tissue is found in the gut wall of animals, blood vessel walls and the urinary bladder wall.

Involuntary muscle cells have a *single* nucleus and contract *slowly*, and tire or fatigue slowly.

Involuntary movements occur in the eye iris and *peristalsis* of gut (Fig. 14.11), uterus and ureters.

(ii) *Heart movement*

Heart muscle contracts *rhythmically* by means of an in-built stimulus. The muscle does *not* tire or fatigue (see Fig. 9.9).

fig 14.10 *smooth, involuntary, or non-striated, muscle tissue of the gut and bladder wall*

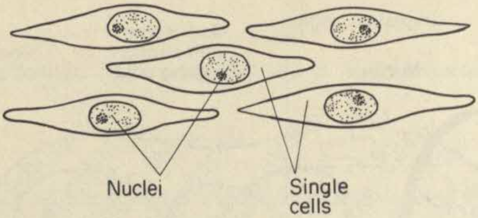
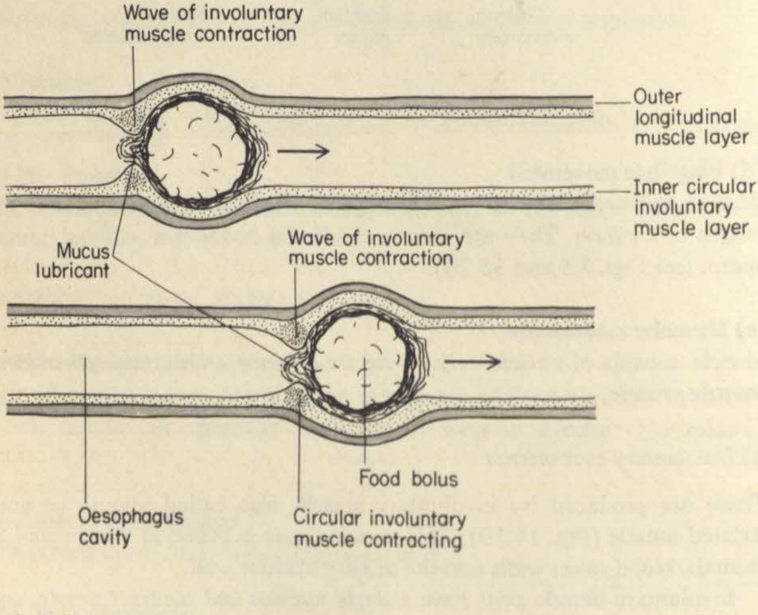


fig 14.11 *peristalsis in the oesophagus due to sequential contraction of the involuntary circular muscle*

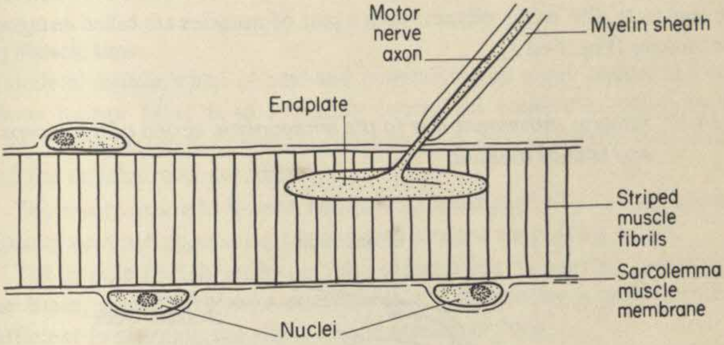

Wave of involuntary muscle contraction
Outer longitudinal muscle layer
Inner circular involuntary muscle layer
Mucus lubricant
Wave of involuntary muscle contraction
Food bolus
Oesophagus cavity
Circular involuntary muscle contracting

(iii) *Voluntary movements*

These are produced by *skeletal* muscle also called voluntary or striated muscle (Fig. 14.12). This muscle is always connected to bones, forming a *musculoskeletal* system.

Skeletal muscle is a syncytium composed of *many* nuclei in a cytoplasm called *sarcoplasm*. It shows cross-stripes or cross-striations, and contains many mitochondria.

fig 14.12 *skeletal, voluntary, or striated, muscle tissue*



Skeletal muscle contracts under the control of the central nervous system and brain *motor* area. The muscle contraction is *sudden* and powerful, and is subject to rapid tiring or fatigue.

14.6 SKELETAL MUSCLE

The human body consists of 45% by weight of *muscle* and 15% *bone*; the remaining 40% is made up of the *organs* such as lungs, liver, etc., and body fat.

Muscles are connected to bones by *tendons*; these join with the fibrous outer layer of bones called the *periosteum*. Tendons are similar to *fibrous* ligaments in being non-elastic and composed of *collagen* protein.

The point where a muscle is connected to an *immovable* bone is called the point of *origin*; the *movable* bone connects by a tendon at the point of *insertion*.

(a) Muscle contraction

Skeletal muscle is composed of tiny *muscle fibrils*. These are collected together and arranged lengthwise in a *bundle* of fibres. Several bundles of muscle fibres surrounded by a muscle *sheath* make up a whole muscle such as the upper arm *biceps* muscle.

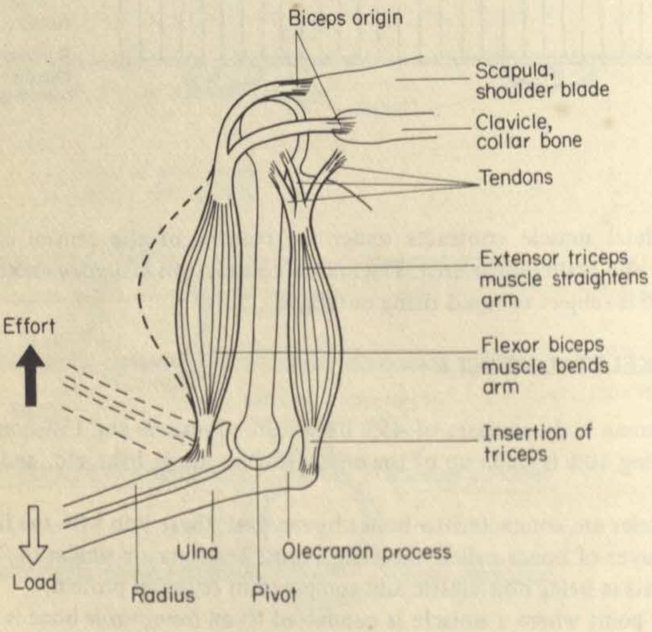
Motor neurones end as motor *endplates* in the muscle fibre. The nervous impulse releases a *chemical transmitter* which crosses the synapse (see Section 13.10). The chemical transmitter releases *energy* from ATP causing the *whole* muscle to contract.

14.7 HUMAN BODY SUPPORT

(a) Antagonistic muscles

Muscles act in pairs, each opposing the action of the other in the pair. As one contracts, the other relaxes; such a pair of muscles are called *antagonistic* muscles (Fig. 14.13).

fig 14.13 *forearm movement due to the antagonistic action of the biceps and triceps muscles*



There are a great number of skeletal muscles in the human body. The following are names given to the main antagonistic muscles and their actions:

(i) *flexors* – bend a limb at a joint, and
extensors – straighten a limb at the joint;

(ii) *abductors* – move a limb away from the body, and
adductors – move a limb towards the body.

(b) Receptors

There are receptors in muscles, tendons, ligaments and joints detecting movement and tension changes.

Muscles have *stretch receptors* that inform the central nervous system (CNS) of the *state of contraction* of the muscle, i.e. whether it is contracted or relaxed. The skin of the feet has *pressure* receptors detecting changes in the body position.

(c) Muscle tone

A skeletal muscle when at *rest* and maintaining an erect posture in a conscious human being is in a slightly contracted condition, called *muscle tone*. If the person becomes *unconscious* or is *asleep*, muscle tone is lost, and the muscles relax completely.

The *erect posture* in human beings is achieved partly by the leg extensor muscles contracting, making the legs into straight supporting pillars.

The muscle stretch receptors relay information by *negative feedback* to the brain, which supplies a stimulus to the muscle by a motor neurone sufficient to maintain the slight muscle tension or tone.

The force of gravity will tend to pull or *bend* the body. Consequently, the limb-straightening, quadriceps extensor muscles will contract and are called the 'antigravity muscles'. Complete body support is achieved by contraction of neck, back, thigh, hip and buttock *extensor* muscles.

The *eyes* and ear *balancing organs* support the muscle receptors in their combined function of maintaining an erect posture (Section 13.6).

14.8 LEVERS IN LOCOMOTION

The movement of the *whole* body, as in walking, running, swimming or flying, is called *locomotion*.

The power to move the body comes from contraction of skeletal muscles which contract by about 30-40% of their resting length; this contraction is on top of *muscle tone*.

Levers in the body are rigid bones turning about a fixed point called the *pivot*, by means of muscle contraction *effort*, resulting in a force which causes movement of a *load*.

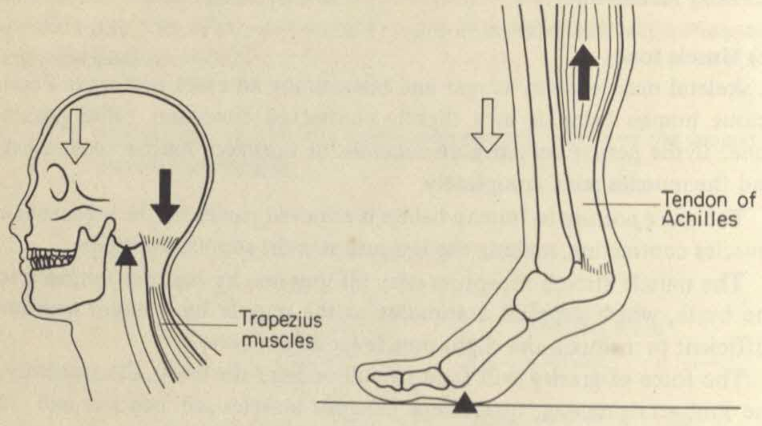
The following are examples of the different *orders* of levers working in the human body (Fig. 14.14).

(a) First-order levers

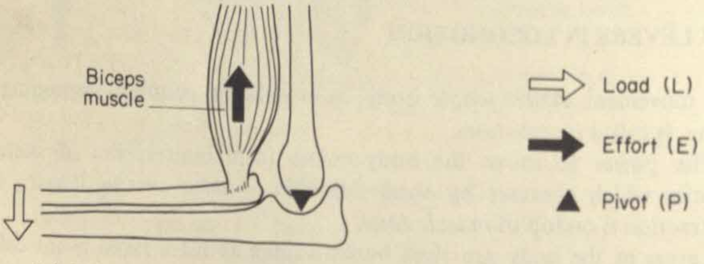
The pivot is between the load and effort (L–P–E), e.g. the head (L) on the atlas axis (P) moved by a neck muscle (E). This type of lever requires a small effort to move a large load.

(b) Second-order levers

The load is between the pivot and effort (P–L–E), e.g. the calf muscle fig 14.14 *different types of levers in the human body*



(a) First-order lever, L-P-E (b) Second-order lever, P-L-E



(c) Third-order lever, L-E-P

(E) lifts the body weight (L) on the toes (P) as in walking or standing on tiptoe. The effort almost equals the load.

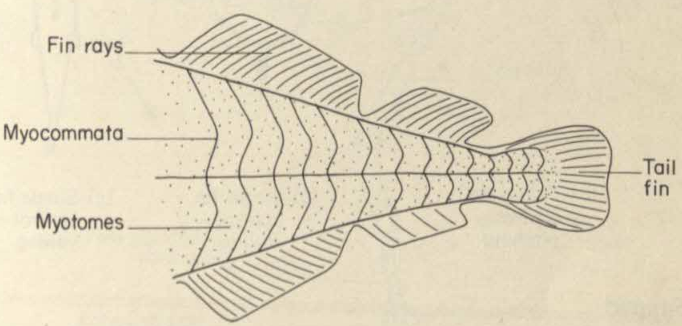
(c) Third-order levers
The effort is between the load and pivot (L-E-P), e.g. the forearm flexor muscle, where the biceps (E) causes a weight (L) to be lifted by a movement at the elbow (P). A large effort is needed to move or lift a small load.

14.9 LOCOMOTION IN WATER – FISH

(a) Propulsion

Skeletal muscle blocks called *myotomes* are arranged on the right and left sides of a flexible vertebral column (Fig. 14.15), each *side* acting *antagonistically*. As the right side muscles contract, the left side muscles relax, causing the body to bend towards the left. This continues as a *wave* of contraction down the length of the body to reach the *tail*. The tail *fin* provides a powerful pushing force or thrust against the surrounding water, the resultant action being a *forward* movement of the whole fish.

fig 14.15 *muscle blocks or myotomes in a bony fish*



(b) Body shape

A fish has a streamlined body shape with a *rounded* front head and *tapering* body finishing as a *pointed* tail (see Fig. 2.18).

A *smooth* body surface helps to reduce drag. The fish scales provide the essential smooth surface, whilst the slimy mucus provides lubrication.

(c) Stability

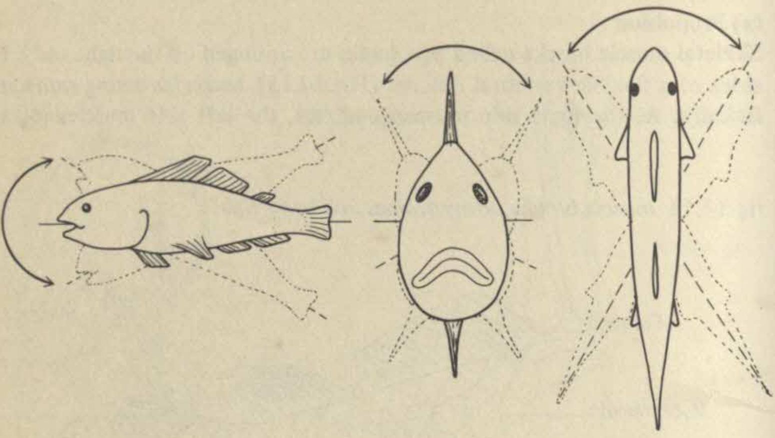
Fish have *paired* pectoral and pelvic fins, together with *single* vertical fins; these are located on the midline position of the back and ventral surfaces. Fins maintain *stability* and control the *direction* of motion (Fig. 14.16).

Pitching is the alternate rising and falling of the head and tail and is controlled by the pectoral and pelvic fins.

Rolling is the twisting or turning motion controlled by all fins.

Yawing is the sideways swaying of the body in going off course. This is counteracted by the body flat sides and the single vertical fins.

fig 14.16 *fins in fish stability control*



(a) Paired fin control — pitching

(a) Single fin control — rolling

(c) Single fin control — yawing

(d) Support

The paired fins acting as hydroplanes generate *lift* by the flow of water over the inclined fins; this can help the fish to rise in the water. Bony fish are also able to adjust their depth by changing their *buoyancy* by inflating or deflating the *swim or air bladders*, which are not present in cartilaginous fish.

14.10 LOCOMOTION ON LAND

(a) Earthworm

(i) *Body shape*

Body shape is tapering and its surface is lubricated, by mucus secreted by the skin, to penetrate the soil and overcome soil *friction* forces.

(ii) *Propulsion*

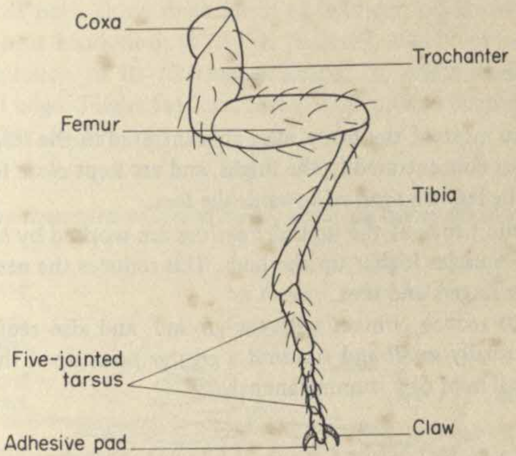
Propulsion is by means of alternate contraction and relaxation of the *antagonistic muscles*, the circular and longitudinal body wall muscles, which pass down the length of the body in waves (Section 14.2).

Chaetae are inserted into the soil to act as pivots. The *effort* in contraction of the longitudinal muscle results in movement of part of the body *load* towards the chaetae.

(b) Insects

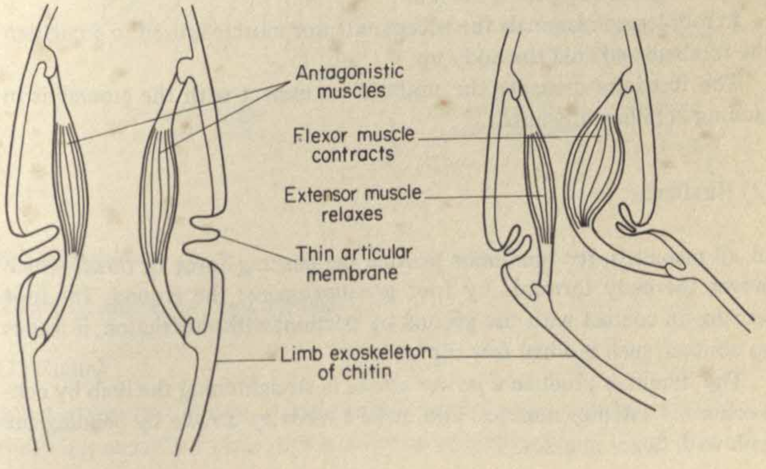
Insects have *six* legs, each of which is a *tube* of chitinous exoskeleton material. The several parts of each leg are connected by flexible *joints* with a peg and socket *pivot* (Fig. 14.17).

fig 14.17 *the walking leg of an insect*



Inside each limb section are pairs of *antagonistic* muscles called extensors and flexors. Each muscle acts *across* the joint between leg sections (Fig. 14.18).

fig 14.18 *antagonistic muscles in an insect responsible for leg movement*



A walking insect will have *three* legs in contact with the ground at any one time, two on one side and one on the other in a tripod. Other arthropods may *leap*, such as for example the flea and grasshopper, or *swim*, such as a water beetle, or *crawl*, such as the centipede.

(c) Mammals

(i) *Body shape*

Mammals have most of the body mass concentrated in the *trunk*. The *legs* have their mass concentrated in the thighs, and are kept *close* to the trunk. The ends of the legs are *tapered* towards the feet.

The feet and hands at the limb *extremities* are worked by *long* tendons connected to muscles higher up the limb. This reduces the need for heavy muscles in the fingers and toes.

In order to reduce contact with the ground, and also reduce friction, the feet are usually *small* and transmit a *greater* pressure or thrust such as through a small hoof of a running animal.

(ii) *Propulsion*

(1) Forelimbs

In human beings the forelimbs or arms are used for lifting weights. The *biceps* or flexor muscle bends the arm at the elbow, whilst the *triceps* or extensor muscle straightens the limb.

In four-legged mammals the triceps extensor muscle is used to straighten the forelimb and hold the body up.

The forelimbs dissipate the upthrust on impact with the ground as in landing or falling forwards.

(2) Hindlimbs

In all mammals, the hindlimbs provide the pushing force or *thrust* which moves the body forwards by foot pressure against the ground. The foot remains in contact with the ground by friction; without friction, it makes no contact, such as when feet slip on ice.

The hindlimb produce a *power stroke* in straightening the limb by contraction of extensor muscles, and make a *recovery stroke* by bending the limb with flexor muscles.

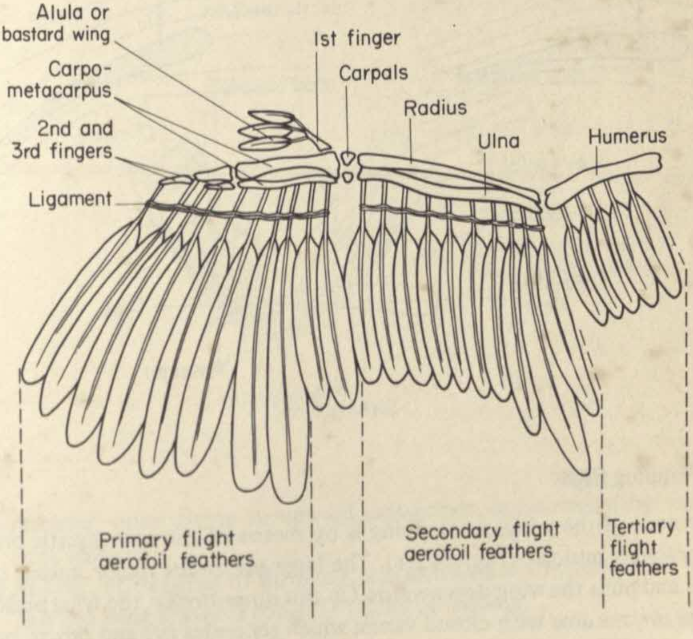
14.11 LOCOMOTION IN AIR – BIRDS AND INSECTS

(a) Birds

(i) *Body shape*

A bird's body is streamlined and has a smooth surface provided by the feathers. Birds have three main kinds of feathers: (a) *down*, small fluffy feathers for heat insulation; (b) *covert feathers*, which cover all the body and provide much of its streamlined shape; (c) *flight feathers*, forming the wing out edge. Flight feathers have a short *quill*, a central *shaft* with a broad vane (Fig. 14.19).

fig 14.19 *the structure of a bird's wing showing bones and flight feathers*



(ii) *Propulsion*

This is by *gliding* or *flapping* flight.

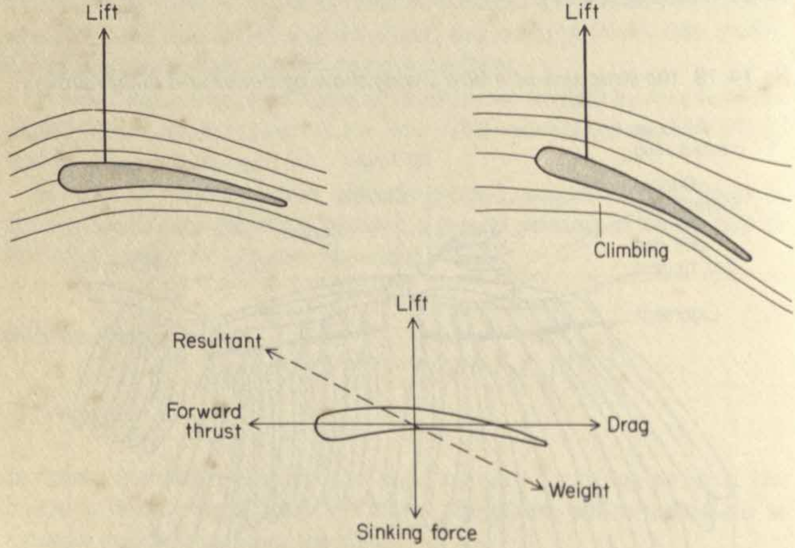
(1) Gliding

A wing seen in section at right-angles to the wing *span* has a sectional shape like an *arched* plate; this is called an aerofoil.

In gliding, the wing is *tilted* with its front or *leading* edge slightly above the *trailing* or back edge. As air flows past the wing, it causes *drag* along the trailing edge.

The combined effect of *lift* and *drag* exactly balances the bird's weight (Fig. 14.20). In time, a gliding bird will lose height unless it experiences changes in wind speed or encounters warm air currents, when they soar upwards on *isothermals*.

fig 14.20 *forces acting on a wing aerofoil during gliding in still air*



(2) Flapping flight

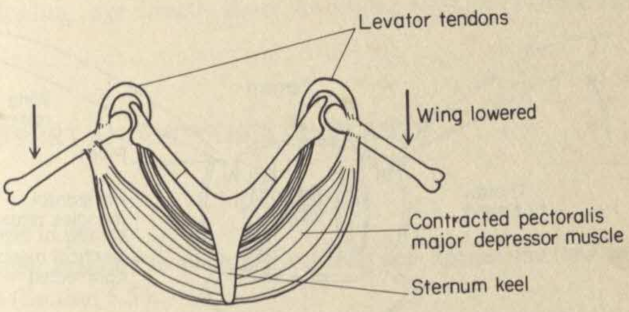
Movement of the wings in flapping is by means of the antagonistic breast or *pectoralis* muscles (Fig. 14.21). The large *pectoralis major* muscle contracts and pulls the wing downwards. On this *downstroke*, the wing presents a large *surface area* with closed vanes, which generates *lift* and *thrust*, pushing the body forwards.

The contraction of the small *pectoralis minor* muscles produces the wing *upstroke*, when the flight feathers *part*, allowing air to pass without resistance between the vanes, and decreases any downthrust.

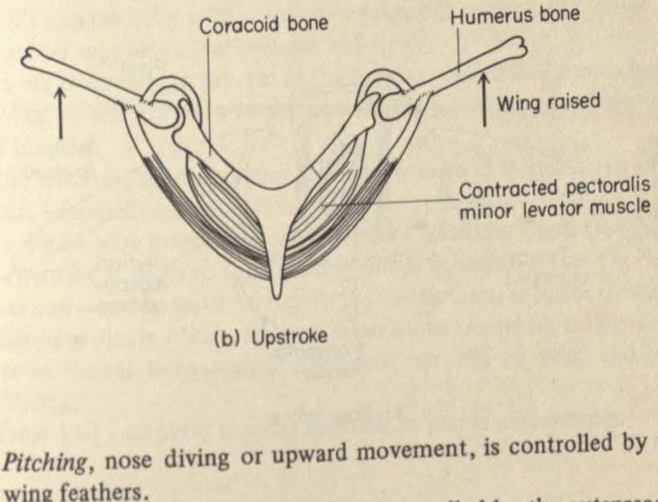
(i) *Stability*: winds affect the stability of birds in the same way as water currents affect fish.

(ii) *Yawing*, or sideways swaying off course, is controlled by the tail feathers.

fig 14.21 *antagonistic muscles responsible for the up-and-down, flapping movement of a bird's wing*



(a) Downstroke



(b) Upstroke

(iii) *Pitching*, nose diving or upward movement, is controlled by tail and wing feathers.

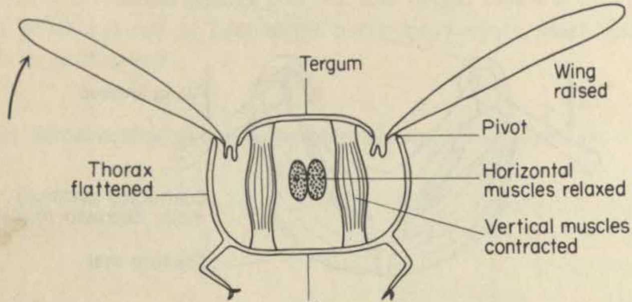
(iv) *Rolling*, or twisting of the body, is controlled by the outspread wings. Tail and wing feathers control braking in landing.

(b) Insects

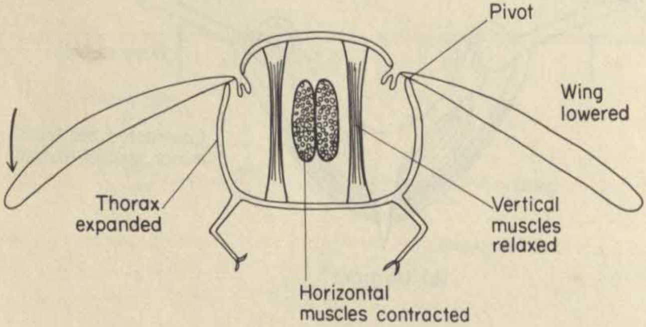
Insect wings are thin *flat* plates of chitinous material stiffened by ribs or veins. They are seen to have an arched aerofoil structure in part of the downstroke.

Insects do not glide, they generate *lift* and *thrust* propulsion force by flapping using flight muscles which are of two kinds, depending on the type of insect (Fig. 14.22).

fig 14.22 *antagonistic muscles responsible for the up-and-down flapping movement of an insect's wing (housefly,* Musca domestica, *and Tse-tse fly,* Glossina *sp.*



(a) Upstroke



(b) Downstroke

(i) *Direct flight muscles*

These are a pair of antagonistic muscles called *depressor* and *elevator* muscles, joined to *large*, *slow*-beating wings as in butterflies, locust and dragonflies. The muscle *origin* is in the thorax sternum.

(ii) *Indirect flight muslces*

The *elevator* muscles are connected between the upper tergum and lower sternum of the thorax; their contraction raises the wing on the upstroke. The *depressor* muscles are connected *longitudinally* in the thorax and their contraction lowers the wing on the downstroke. This type of flight muscle is seen in insects with *small*, *fast*-beating wings such as housefly, wasp and bee. The insect wing on the downstroke has an aerofoil profile for maximum lift and thrust. On the upstroke the wing is turned vertically with the leading edge directly above the trailing edge for the least resistance and lift.

14.12 SUPPORT AND MOVEMENT IN PLANTS

(a) Support in plants

Water turgor pressure in plant cell vacuoles acts against the rigid cellulose cell walls (Section 5.5).

Epidermis layers surround the multicellular plant providing a firm layer maintaining the plant shape and withstanding the outward-acting pressure generated by inner tissues.

Collenchyma cells with cellulose thickening in the cell corners provide *mechanical* support in leaf petioles and stems.

Lignin thickening is present in the tubular mechanical supporting tissues of xylem vessels and in *sclerenchyma* fibres protecting the phloem of vascular bundles.

The *mechanical supporting* tissue (Sections 3.9 and 3.10) of collenchyma, sclerenchyma and xylem vessels is arranged:

(i) *cylinder-wise* in stems to resist bending forces by winds (see Fig. 3.12);
(ii) *centrally* in roots to resist pulling forces or tensions (see Fig. 3.13);
(iii) as a *network* to resist tearing forces by the wind in leaves (Section 6.4).

Climbing plants obtain support from other plants by means of *twining stems* in runner bean and honeysuckle, *tendrils* in peas, and *hooks* in blackberry.

Table 14.1 compares support methods in plants and animals.

(b) Movement in plants

Plants are static and firmly rooted in the ground, and have no need for methods of locomotion, essential to animals to obtain food, and to find a mate in reproduction.

Taxic movements are seen in *Chlamydomonas*, and *Euglena*, and also in certain bacteria.

Tropic growth movements are described in Section 11.10.

Mechanical movements occur in the opening of fern sporangia, and certain ripe fruits such as legumes; these are *hygroscopic* movements due to water absorption (see Fig. 15.5).

Table 14.1 *comparison of support in plants and animals*

	Plants	*Animals*
1	Firm cell *cellulose* wall – epidermis	Flexible plasma membrane
2	*Turgidity* by high osmotic pressure (wilting = low osmotic pressure). Parenchyma cells of pith and cortex	*Hydrostatic skeleton* of fluid under pressure surrounded by muscles – *Hydra*, earthworm
3	*Cellulose* thickening in collenchyma cells – herbaceous plants	*Exoskeleton* as outer *shell* in molluscs, or as *cuticle* in insects
4	*Lignin* thickened cells in sclerenchyma fibres and xylem vessels of *woody* stems	*Endoskeleton* of bone and cartilage in vertebrate animals, together with skeletal muscle in posture
5	*Climbing* plants obtain support by twining stems, tendrils, thorns and prickles	Aquatic and flying animals obtain *lift* in various ways. Land animals have supporting *stances*
6	*Stems* resist *bending* force – support *cylindrical*. Roots resist *pulling* force – support *central*. Leaves resist *tearing* force – support a *network* of veins	Skeleton support is mainly *central*

14.13 QUESTIONS

1 Draw a labelled diagram to show the tissues which provide support in a herbaceous stem. Explain the importance of turgor in unicellular and multicellular plants.

2 Why do most animals move from place to place whilst most land plants are rooted and fixed? What methods are used by flowering plants to reach more favourable positions or habitats?

3 Describe by means of a labelled diagram the structure of a movable joint in the mammal skeleton.

4 Name the three main types of muscle found in the mammal body. What chemical substance causes the muscles to act? Illustrate how a pair of antagonistic muscles causes movement in a mammal limb.

5 Compare the similarities and differences in the functions of a mammal skeleton and an insect exoskeleton.

6 Describe five features of a bird which adapt it to flight.

7 Draw a labelled diagram showing the external features of a bony fish. Describe how a fish can change its position by means of (a) the fins, (b) the tail, and (c) the swim bladder.

CHAPTER 15

REPRODUCTION

15.1 INTRODUCTION

Organisms have a varied *lifespan* from a few hours to many years. Each organism undergoes a *life-cycle* from the time of its formation from either *one* or *two* parents, until its death.

Reproduction is a characteristic of living organisms essential to the continuation of *life*, and in the continuation of the *species*. The species is a group of organisms able to reproduce amongst themselves, but not with organisms of other species.

Asexual reproduction is a *rapid* method of increasing a species of plants and lower animals from *one* parent.

Sexual reproduction is a slower method and usually less prolific in increasing plant and animal species from *two* parents (one in *hermaphrodite* tapeworm).

15.2 ASEXUAL REPRODUCTION

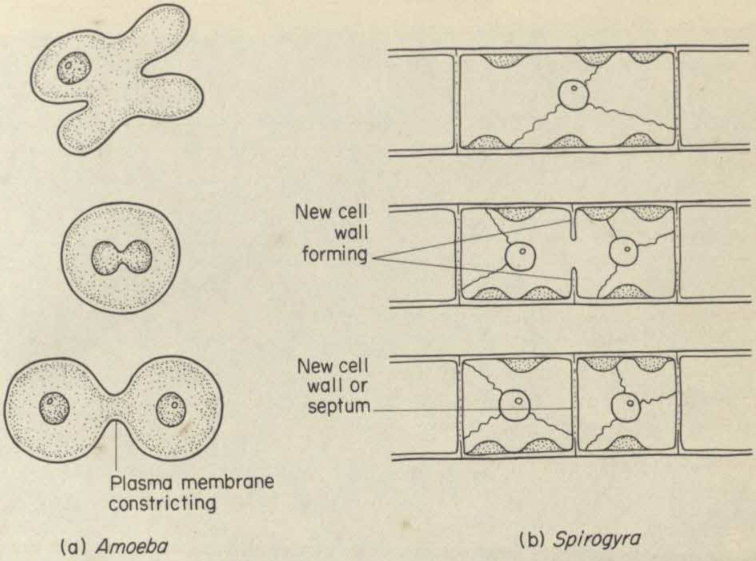
In asexual reproduction the *nucleus* divides by *mitosis* (Section 11.2), producing daughter cells each having the *same* number of chromosomes in their nuclei as the parent cell.

The following are the main methods of *cell* division involving the whole body of the simpler unicellular plants and animals.

(a) Binary fission

Binary fission is seen in *Amoeba* (Fig. 15.1a), *Paramecium* and bacteria, when the *cytoplasm* divides into two equal parts after nuclear division. The process occurs when the parent cell has reached a certain size.

fig 15.1 *asexual reproduction methods in (a)* Amoeba *sp. and (b)* Spirogyra *sp.*



(a) *Amoeba* (b) *Spirogyra*

(b) Septation

Septation is seen in *Spirogyra* (Fig. 15.1b) and algae when a parent cell divides by forming a new *cell wall* or *septum* to separate two daughter cells.

(c) Budding

Budding is seen in its simplest form in yeast (Plate 15.1), when the cell forms a *small* bulge into which cytoplasm and a nucleus pass. The bud is much smaller than the parent cell and becomes detached.

Hydra, a multicellular organism, forms a bud which later separates from the parent (Fig. 15.2).

Tapeworm shows budding of *proglottids* from a neck of the scolex (see Fig. 2.11).

(d) Spore formation

Fungi, liverworts, ferns and mosses can produce enormous numbers of *spores*.

(i) *Bacterial spores*

Certain bacteria form a thick-walled *spore* inside the bacterial cell wall (Fig. 15.3). This, like most spores, can resist unfavourable conditions, plate 15.1 *a photomicrograph showing yeast,* Saccharomyces *sp. cells in the process of budding (The Distillers Co. Ltd)*

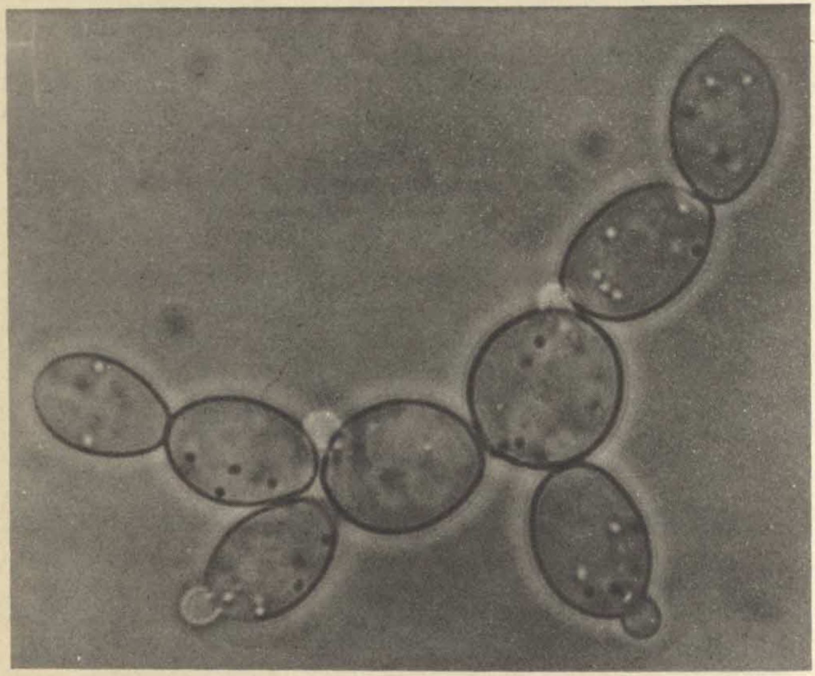


fig 15.2 *asexual reproduction by budding in* Hydra *sp.*

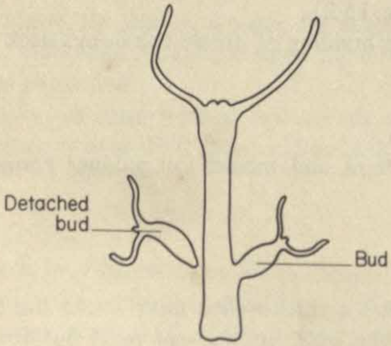
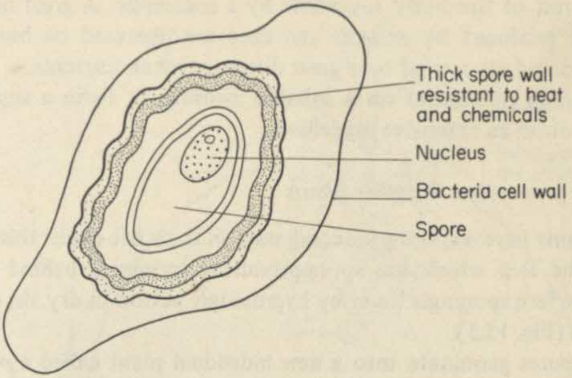


fig 15.3 *a bacteria spore, a means of survival in adverse conditions*

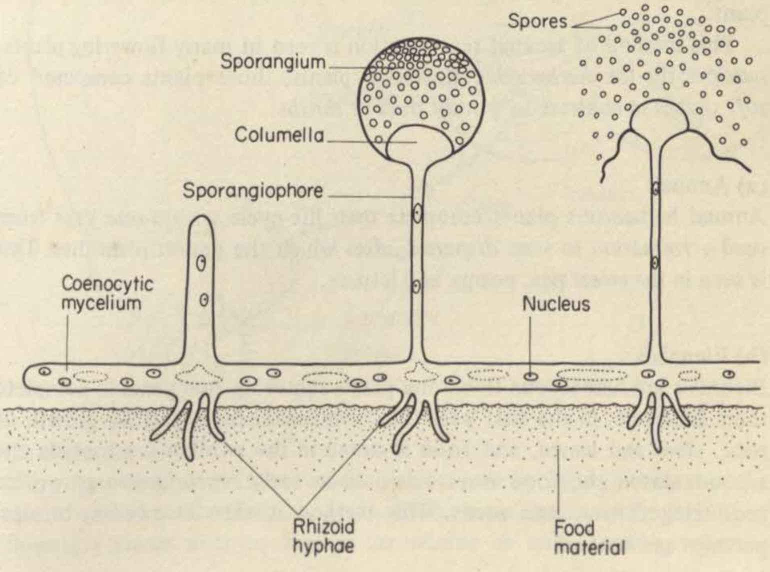


drought and extremes of heat. Many bacteria spores survive cooking temperatures to cause *food poisoning* (Section 19.3). The light spores are carried by air currents to infect *exposed* food or wounds.

(ii) *Spore-producing sporangia*

Mucor or the pin mould found on decaying bread and fruit is able to produce a single *hypha* from its body or *mycelium* (Fig. 15.4). This

fig 15.4 *method of asexual reproduction by spore formation in pin mould,* Mucor *sp.*



erect hypha develops a swelling at its tip to form a *sporangium* separated from the rest of the body mycelium by a *columella*. A great number of *spores* are produced by *mitosis* and they are liberated on bursting the sporangium and are carried over great distances by air currents.

Each spore *germinates* on a suitable medium to form a small hypha which produces an extensive mycelium.

(iii) *Spore production in higher plants*

Higher plants have a spore-producing stage in their life-cycle; this is clearly seen in the fern which has spore-producing *sporangia* behind the leafy *frond*. The fern sporangia burst by hygroscopic action in dry air, scattering the spores (Fig. 15.5).

Fern spores germinate into a new individual plant called a *prothallus*, which reproduces sexually to form a zygote. This becomes another individual plant with the leafy frond which reproduces *asexually* in a *sporophyte* plant (Section 15.5).

15.3 VEGETATIVE REPRODUCTION

Vegetative reproduction is a method of *asexual* reproduction in which *vegetative parts* (root, stem, leaf or bud) become detached from the parent plant body and then develop into another complete daughter plant.

This method of asexual reproduction is seen in many flowering plants, particularly the *herbaceous* flowering plants, those plants composed of *soft* tissues in contrast to woody *trees* or *shrubs*.

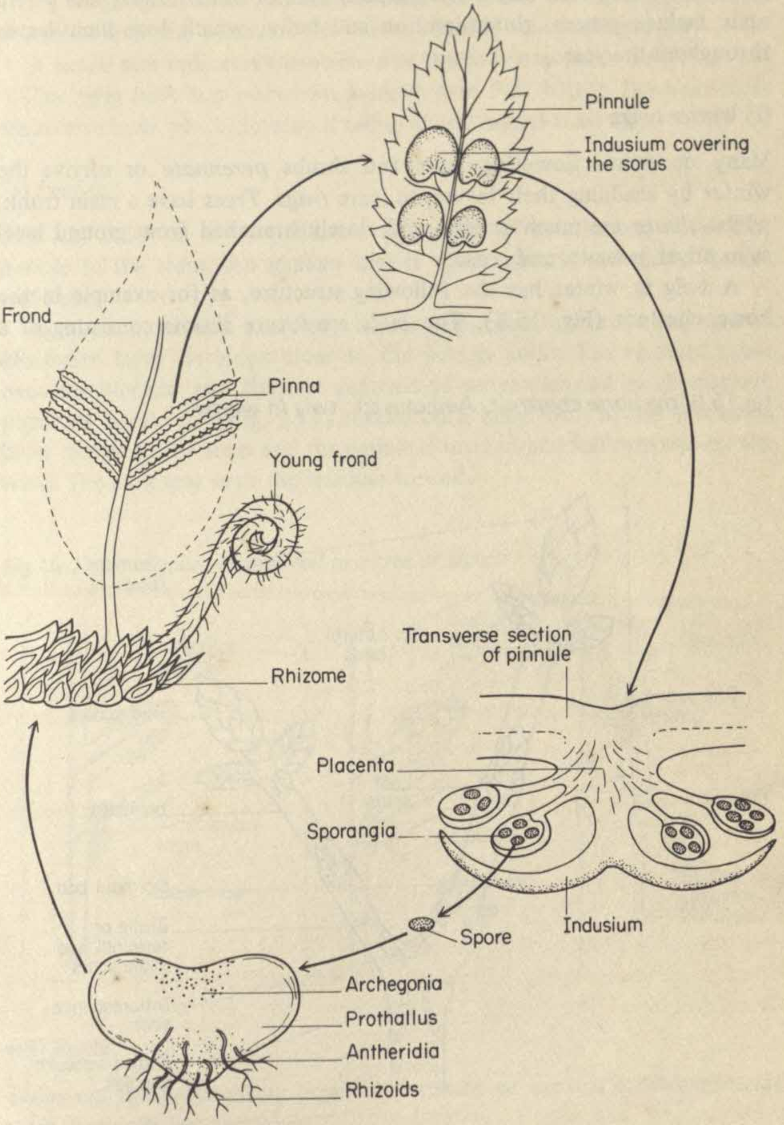
(a) Annuals

Annual herbaceous plants complete their life-cycle within *one* year from seed *germination* to seed *dispersal*, after which the parent plant dies. This is seen in the sweet pea, poppy and lettuce.

(b) Biennials

Biennials are herbaceous flowering plants requiring *two* years to complete their life-cycle. In the first year the carrot produces *vegetative* growth of root, stem and leaves, and food is stored in the swollen tap root. In the second season the food reserve is used in early *reproductive* growth in producing flowers and seeds. This method is seen in swedes, turnips, parsnips and beet.

fig 15.5 *the fern*, Dryopteris *sp., life-cycle*



(c) Perennials

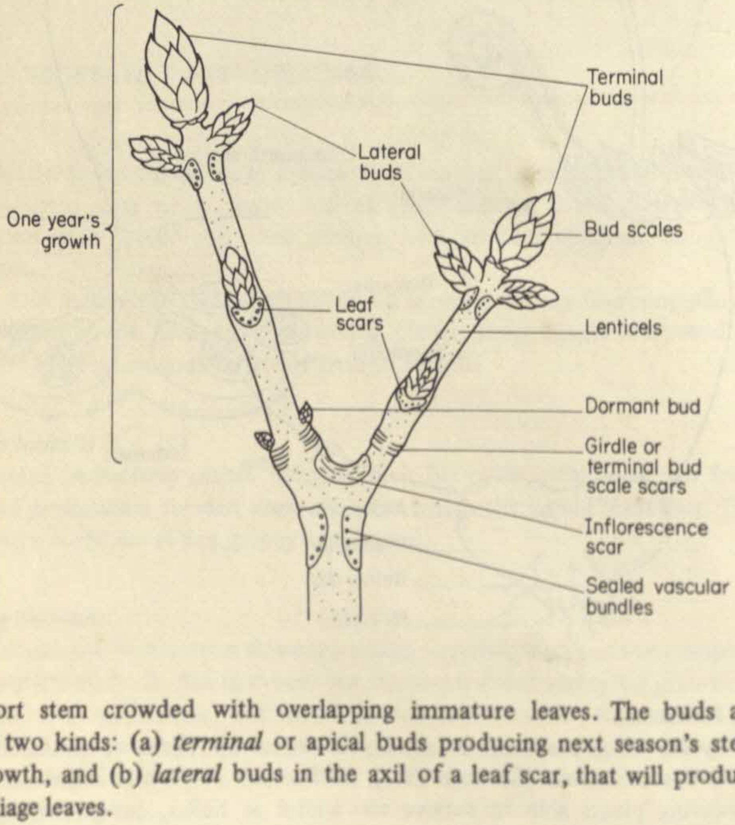
Many flowering plants survive from year to year by *vegetative* means other than dormant seeds (Section 11.4). *Herbaceous* perennials include those flowering plants able to survive the winter as bulbs, corms, tubers or rhizomes. *Woody* perennials are those flowering plants which survive winter by losing their leaves as *deciduous trees* or *shrubs*. *Evergreen* perennials include grasses, rhododendron and holly, which lose their leaves throughout the year.

(i) *Winter twigs*

Many deciduous flowering trees and shrubs *perennate* or survive the winter by shedding their leaves, to leave *twigs*. *Trees* have a main trunk, whilst *shrubs* are much smaller and closely branched from ground level as in privet, lavender and gorse.

A twig in winter has the following structure, as for example in the horse chestnut (Fig. 15.6). The *buds* are future shoots consisting of a short stem crowded with overlapping immature leaves. The buds are of two kinds: (a) *terminal* or apical buds producing next season's stem growth, and (b) *lateral* buds in the axil of a leaf scar, that will produce foliage leaves.

fig 15.6 *the horse chestnut,* Aesculus *sp., twig in winter*



The buds are protected by sticky, waterproof bud scales; these leave a ring or girdle of *scale leaf scars* around the base. The distance between one set of scale leaf scars and the next is equal to one year's growth.

A *saddle* scar indicates the position of the previous year's flowers.

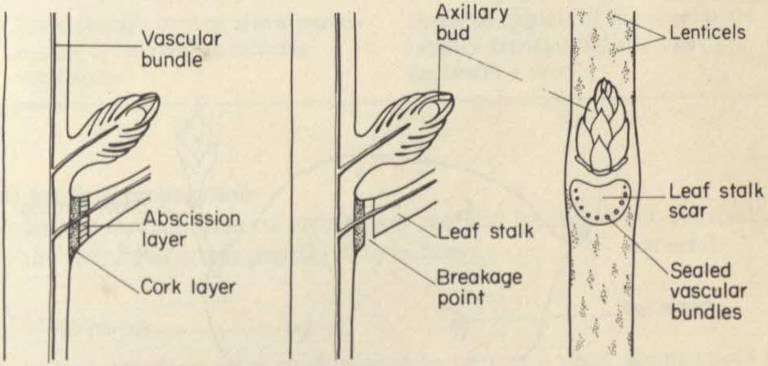
The twig *bark* has numerous *lenticels* (see Fig. 10.12). *Dormant* buds are reserve buds which develop if terminal and lateral buds die.

(ii) *Leaf fall*

The *leaf scars* on a twig indicate the point of attachment of the *leaf petiole* to the stem. An *axillary* bud is always positioned in the former leaf axil.

In autumn, certain *excretory* wastes, e.g. tannins, enter a leaf and an *abscission* layer develops close to the petiole stalk. The vascular tissue becomes blocked and the leaf deprived of water dies and its chlorophyll pigments break up (Fig. 15.7). Loose cork cells form in the abscission layer closest to the stem and the petiole is severed and leaf removed by the wind. The cork scar seals the leaf scar wound.

fig 15.7 *the process of leaf fall in a tree or shrub*

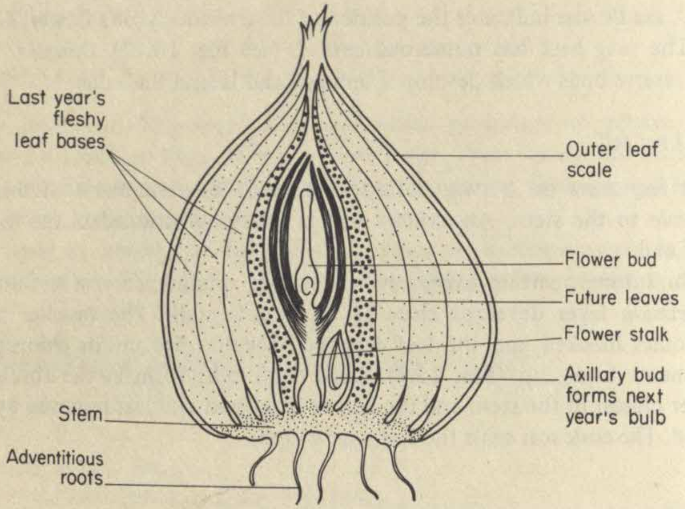


(iii) *Bulbs*

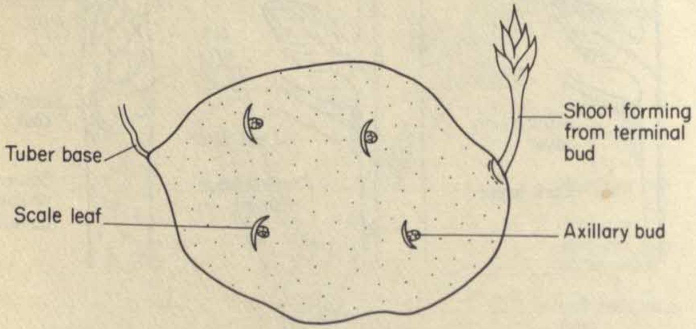
Bulbs are the perennating organs and means of asexual reproduction of tulip, hyacinth and snowdrop.

Bulbs are swollen underground buds in which the small disc-shaped stem bears a number of leaves with fleshy bases swollen with food reserves (Fig. 15.8a). Between the fleshy foliage leaves are small *axillary buds*. A central *terminal* bud develops into the overground flower and shoot, using the food reserve for early spring growth.

fig 15.8 *(a) the bulb and (b) the tuber as examples of vegetative reproductive organs*



(a) Tulip



(b) Potato

Food made by photosynthesis swells the *axillary* buds to form a number of daughter bulbs from one parent bulb. Reproduction therefore occurs by planting one bulb which at the end of its life-cycle produces a number of daughter bulbs *separating* from the parent by vegetative reproduction, each *individual* bulb perennating by surviving until the spring.

(iv) *Stem tuber*

The potato is a *stem tuber* (Fig. 15.8b) or swollen underground stem identified by its numerous 'eyes' or axillary buds in scale leaf scars. One potato tuber, at the end of its life-cycle, reproduces vegetatively in forming many daughter stem tubers, each of which *separates* from the parent plant, and *perennates* over the winter.

Table 15.1 compares the advantages and disadvantages of vegetative reproduction.

Table 15.1 *comparison of advantages and disadvantages of vegetative propagation*

	Advantages	*Disadvantages*
1	Rapid means of reproduction and 'spread'. Can keep down other species	Overcrowding and competition for space unless separated artificially
2	Offspring identical to parent and to each other. 'Varieties' can thus be preserved genetically in roses, apples, etc.	New 'varieties' cannot be produced by this method except by mutation (Section 16.3)
3	Food storage organs allow perennation or survival in adverse conditions	Diseases typical of the species are rapidly transmitted and can decimate a crop

(d) Artificial propagation

Vegetative reproduction or propagation can also be performed *artificially* by the method of either *grafting* or by *cuttings*.

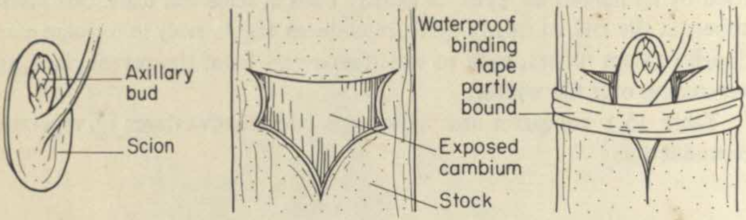
(i) *Grafting*

A graft in the form of a small vegetative part of a plant, for example a *bud* or short *stem apex* (Fig. 15.9), is called the *scion*. This is grafted on a different individual of the *same* species called the *stock*.

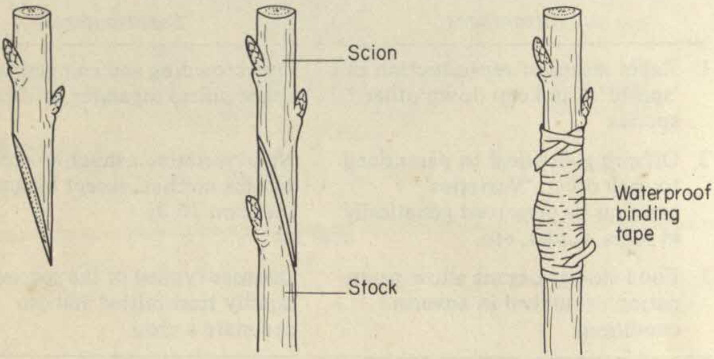
In this way, a herbaceous perennial with certain advantageous features, such as prolific fruiting or certain flower colour, is grafted onto a vigorously growing rooted stock, usually a *wild* variety of the species. For example, apple is grafted onto wild crab apple stock and roses onto wild briar stock.

In grafting, the vascular bundle *cambium* of the stock and scion grow together, the two being bound together at a firmly made *joint* with waterproofed waxed tape.

fig 15.9 *(a) budding and (b) grafting methods of artificial reproduction or propagation*



(a) Budding



(b) Grafting

(ii) *Cuttings*

This is a method of stimulating the formation of *adventitious roots* by means of root-forming *auxins* or plant hormones. Leaves and stems of soft herbaceous or woody perennials can be propagated artificially by leaf or stem cuttings. Dandelions propagate from small portions of root cuttings.

15.4 SEXUAL REPRODUCTION

Sexual reproduction occurs widely in both plants and animals. Some organisms are able to reproduce by both methods. For example, the flowering plant onion is able to reproduce asexually by the vegetative method of forming *bulbs*, or by means of sexually formed *seeds*.

The fusion of the sex cell or *gamete* nuclei takes place in fertilisation to form a *zygote*, which later grows into a new organism.

Individuals may be either *male* or *female*, or *hermaphrodite* in having both male and female reproductive organs as in the tapeworm, earthworm and many flowering plants.

Gametogenesis is the process of forming gametes in plant and animal reproductive organs.

(a) Types of gametes

Isogamous gametes form from the two different sexes and are *identical* to each other in size and shape. This type of sex gamete is seen in algae, protozoa and fungi.

Anisogamous gametes form from the different sexes. The *female* is usually a large non-motile gamete called an *ovum* (plural ova), and it also has a reserve of food. The *male* is small and motile. The fertilisation between anisogamous gametes is called *oogamy*.

(b) Reproductive organs

Plant reproductive organs are called *gametangia* in fungi, and *oogonia* if female ova are produced in algae and fungi. *Archegonia* are the female organs of liverworts, mosses and ferns. *Antheridia* are the male sex organs of algae, fungi, liverworts, mosses and ferns forming *spermatozoids*.

Animal reproductive organs or *gonads* are called *testis* (plural testes), forming spermatozoa, and *ovary* (plural ovaries), forming the ova.

15.5 SEXUAL REPRODUCTION IN NON-SEED-BEARING PLANTS

(a) *Spirogyra*

Sexual reproduction of *Spirogyra* (Fig. 15.10) occurs in the United Kingdom in autumn, between adjacent filaments. Outgrowths from each cell form a *conjugation tube*. Meanwhile the cell contents become rounded off to form *gametes*. One gamete passes along the conjugation tube to fertilise the other, forming a *zygospore* or thick-walled resting spore.

In the spring, the zygospore nucleus divides by *meiosis*, forming new *spirogyra* cells which divide *asexually* by septation.

(b) *Mucor*

Sexual reproduction of *Mucor* (Fig. 15.11) occurs between different *strains* called plus (+) and minus (–) which form *gametangia*, each containing many nuclei. The gametangia meet and the end wall breaks down allowing opposite nuclei to fuse in pairs, forming *zygotes* inside a zygospore.

After several months of dormancy the *zygospore* nuclei divide by meiosis to form a *sporangiophore* on the end of which is a *sporangium*.

fig 15.10 *sexual reproduction in* Spirogyra *sp.*

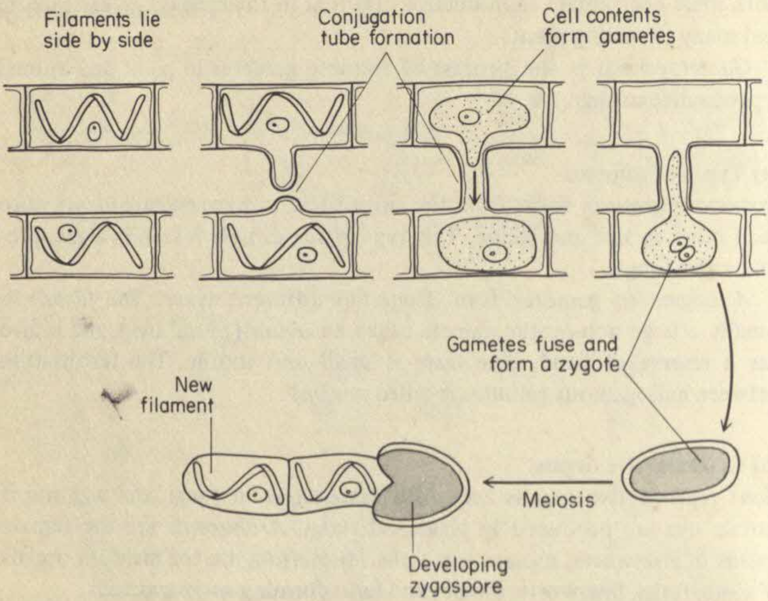
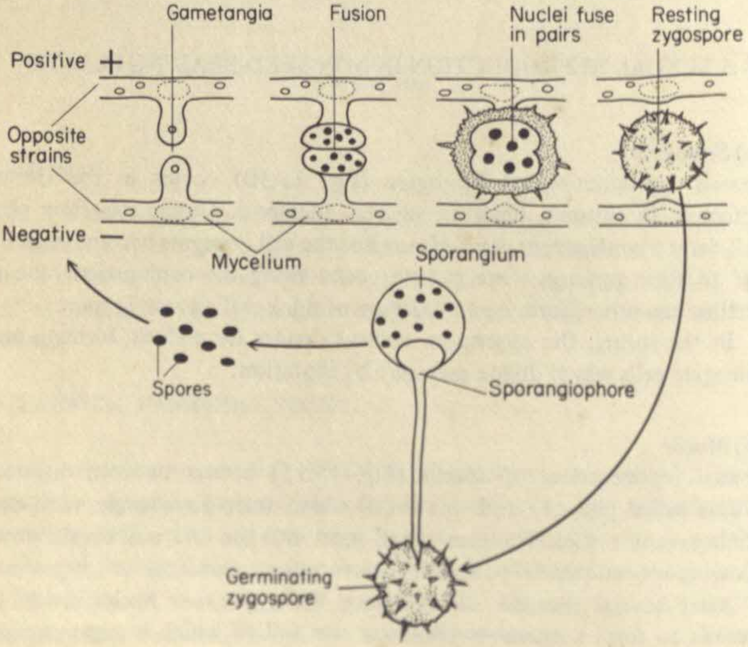

Filaments lie side by side
Conjugation tube formation
Cell contents form gametes
Gametes fuse and form a zygote
New filament
Meiosis
Developing zygospore

fig 15.11 *sexual reproduction in pin mould,* Mucor *sp.*

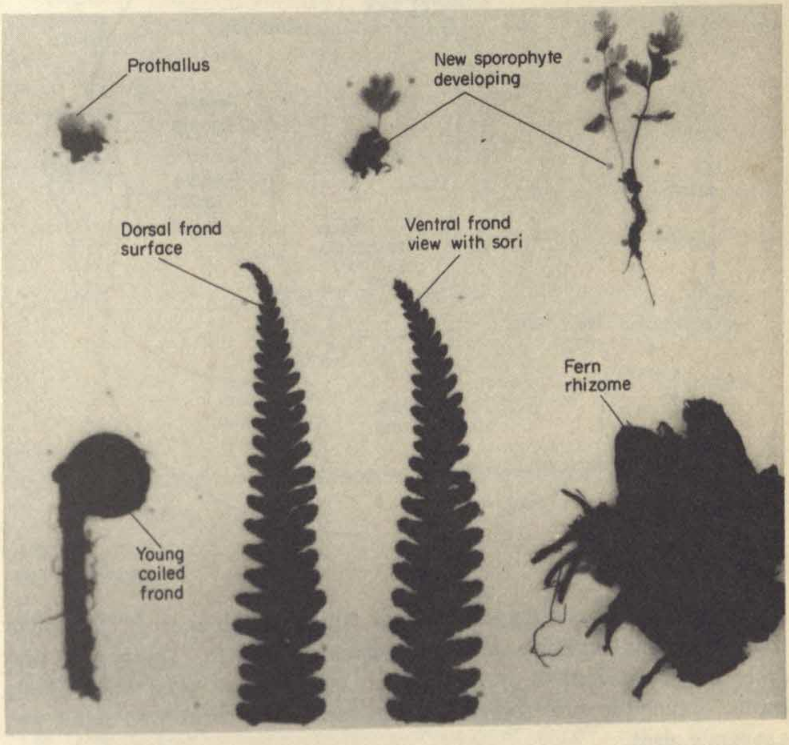


The numerous spores of both + and – strains are carried by air currents on bursting of the sporangium. Each spore germinates on a suitable medium to form a hypha, and then a mycelium in warm, damp conditions.

(c) Moss and fern

The *life-cycle* of fern (Plate 15.2) shows an asexual spore-producing plant called a *sporophyte*, and a sexually reproducing plant called a prothallus, also called a *gametophyte* (see Section 15.2).

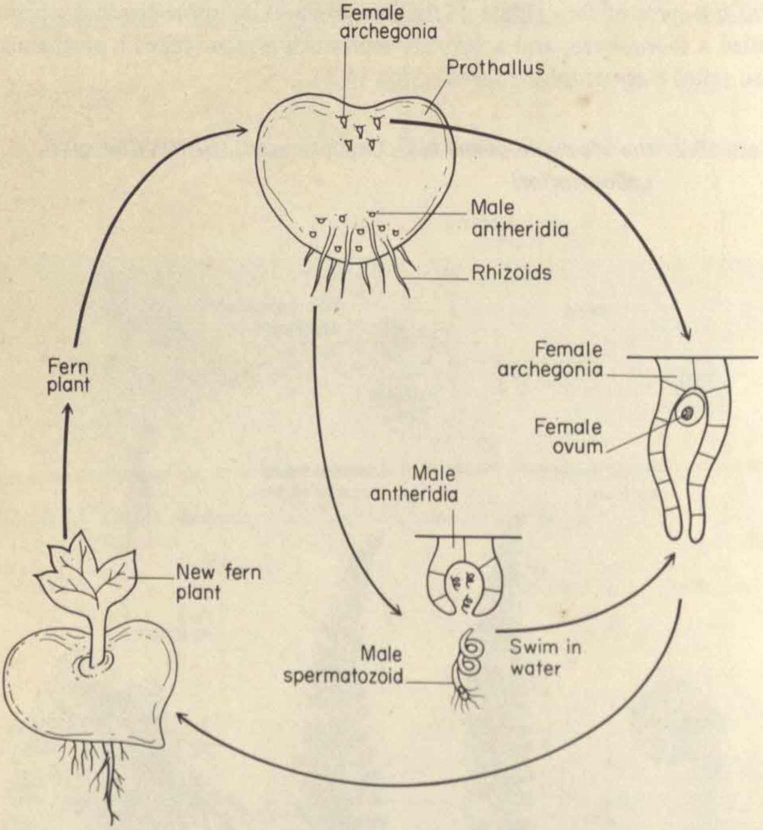
plate 15.2 *the life-cycle of the fern,* Dryopteris *sp. (Griffin Biological Laboratories)*



During the life-cycle of fern, the gamete-producing gametophyte plant makes a zygote which grows into a spore-producing sporophyte plant with its large frond.

The male gametes form in the *antheridia* and are motile spermatozoids which *swim* in the water of the damp environment surrounding the prothallus to reach the female *ova* in the archegonium (Fig. 15.12). Afterwards the zygote germinates in the spring to form the asexual sporophyte plant.

fig 15.12 *sexual reproduction in the fern,* Dryopteris *sp.*



Ferns have a large frond-like plant which is the *sporophyte*, and a small prothallus forming a short-lived *gametophyte* plant. This type of life-cycle shows *alternation of generations*. Mosses have plant bodies with leaves forming the *gametophyte*; the *sporophyte* is short-lived and is not a separate plant.

15.6 SEXUAL REPRODUCTION IN SEED-BEARING PLANTS

About 65% of all known *species*, or kinds of plants, are *seed-bearing plants* able to produce a seed within a *flower* or *cone* as an organ of *sexual* reproduction.

(a) Flower structure

There are over 300 000 different species of flowering plants, each having a different flower structure (Figs 15.13 and 15.14).

fig 15.13 *the structure of a dicotyledon plant flower*

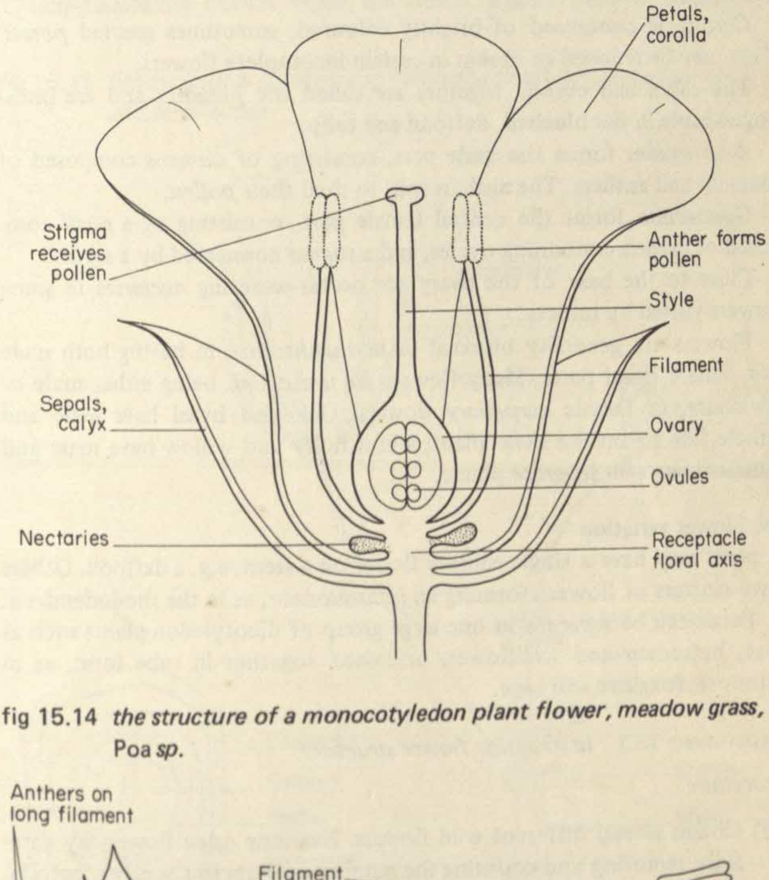
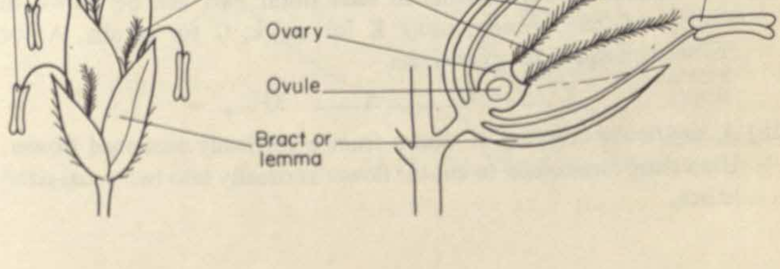


fig 15.14 *the structure of a monocotyledon plant flower, meadow grass,* Poa *sp.*



A *complete* flower will have *four* sets of floral parts arranged in rings attached to a swollen stem tip called the *receptacle*, for example the buttercup flower. An *incomplete* flower may have a set of floral parts missing, as in the grasses.

Calyx is the outermost set composed of mainly green, leaf-like, protective *sepals*.

Corolla is composed of brightly coloured, sometimes scented *petals*. They may be reduced or absent in certain incomplete flowers.

The calyx and corolla together are called the *perianth* and are indistinguishable in the bluebell, daffodil and tulip.

Androecium forms the male part, consisting of *stamens* composed of filament and anthers. The anthers split to shed their *pollen*.

Gynoecium forms the central female part, consisting of a *pistil* composed of carpels containing ovules, and a *stigma* connected by a *style*.

Close to the base of the ovary are nectar-secreting *nectaries* in some flowers visited by insects.

Flowers are generally bisexual or *hermaphrodite* in having both male and female floral parts. Many flowers are *unisexual*, being either male or *staminate*, or female *carpellary* flowers. Oak and hazel have male and female flowers on the *same* plant, whilst holly and willow have male and female flowers on *separate* plants.

(b) Flower variation

A plant may have a single solitary flower on a stem, e.g. a daffodil. Others have clusters of flowers forming an *inflorescence*, as in the rhododendron.

Petals can be *separate* in one large group of dicotyledon plants such as rose, buttercup and wallflower, or *joined* together in tube form, as in primrose, foxglove and sage.

Experiment 15.1 *to examine flower structure*

Procedure

(i) Obtain several different wild flowers. Examine *open* flowers by carefully removing and counting the number of parts in the calyx, corolla, androecium and gynoecium. Note the detailed structure using a hand lens

(ii) The number of components in each floral part can be shown in a simple *floral formula*, using K for calyx, C for corolla, A for androecium and G for gynoecium.

K___ C___ A___ G___

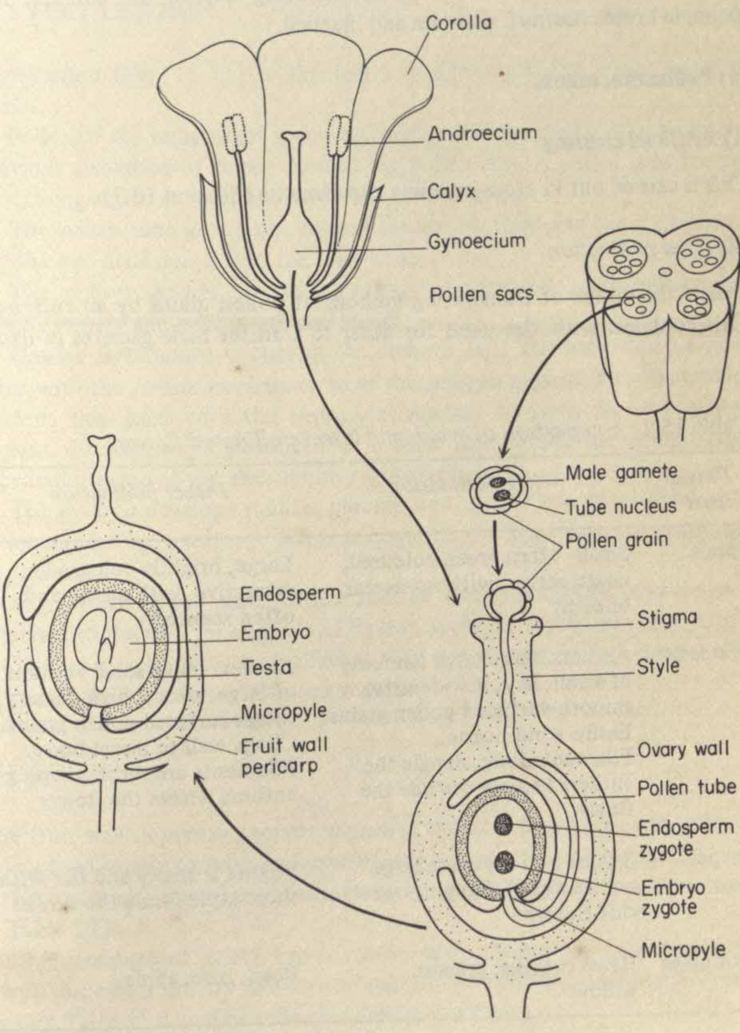
(iii) A *half-flower* diagram is drawn from a vertically sectioned flower. Use a sharp razor blade to cut the flower vertically into two equal-sized halves.

15.7 POLLINATION

Pollination (Fig. 15.15) is the transfer of pollen from anther to stigma. Pollen grains are released from the ripe anthers and can be used in *self-* or *cross-*pollination.

Self-pollination occurs when the flower stigma receives pollen from

fig 15.15 ***life-cycle of a dicotyledon flowering plant, showing pollination and fertilisation***



stamens of the *same flower*, or from stamens of other flowers on the *same plant.* The garden pea, used in heredity experiments, self-pollinates before the flower bud opens.

Cross-pollination occurs when the pollen from the stamens of a flower is transferred to the stigma of another flower of the same species. Cross-pollination will naturally occur between single-sex flowers, e.g. holly and willow.

Protandrous flowers have anthers which ripen before the pistil, for example the dead nettle, dandelion and foxglove.

Protogynous flowers have pistils maturing before the anthers, for example horse chestnut, plantain and bluebell.

(a) Pollination agents

(i) *Artificial crossing*

This is carried out in cross-breeding experiments (Section 16.7).

(ii) *Wind pollination*

This is the means of transferring millions of pollen grains by air currents. This contrasts with the need for *water* to transfer male gametes in liver-

Table 15.2 *comparison of wind- and insect-pollinated flowers*

Flower part	*Wind pollination*	*Insect pollination*
Petals	Small, often green-coloured, unattractive, without nectar, or scent	Large, brightly coloured, attractive, with nectar and often scented
Stamens	Anthers make large amounts of small, dry, low-density, smooth-surfaced pollen grains. Easily wind borne. Filaments long, dangle the anthers loosely *outside* the flower	Anthers make small amount of large, sticky, high-density, rough-surfaced pollen grains. Clings well to insect body. Filaments are short, keeping anthers *within* the flower
Carpel	Stigma and style are large and feathery, hanging *outside* flower	Stigma is sticky and flat with short style *inside* the flower
Examples	Hazel catkins, grasses, willow	Bean, rose, apple

worts, mosses and ferns.

Most trees and all grasses are wind pollinated by pollen of low density.

(iii) *Insect pollination*

This occurs by insects being attracted to flowers by means of their petal colour, scent and nectar. The sticky pollen is of a high density and clings to the insect body bristles or hairs.

Table 15.2 compares insect-pollinated and wind-pollinated flowers.

15.8 FERTILISATION

Fertilisation (Fig. 15.15) is the union of the male and female gamete *nuclei*.

Pollen of the same plant species germinates on the sticky stigma, which provides a solution of sugars to feed the pollen cell. A *pollen tube* forms containing a *tube nucleus* and two *male gamete nuclei*.

The pollen tube grows downwards feeding on tissues of the *style* carrying the *two* male nuclei into the *embryo sac*.

The embryo sac has an opening called the *micropyle*, and contains the *female gamete* and *endosperm cell* nuclei.

Double fertilisation occurs in the embyro sac. The male nucleus first joins with the *female nucleus* to form the *embryo zygote*. The other male nucleus then joins with the *endosperm nucleus* to form the *endosperm zygote*. Endosperm is produced as a food reserve for the embryo by repeated division of the endosperm zygote by *mitosis*.

The *embryo* develops radicle, plumule and one or two cotyledons, and is surrounded by a testa. A *placenta* connects the *seed* with the fruit wall or *pericarp*.

Most other flower parts wither and fall away, but some may remain attached to the *fruit*, as stigma and style in apple, or sepals seen in tomato.

The *receptacle* may become fleshy, as in strawberry, or may completely surround the pericarp or 'core', as in apple.

15.9 FRUITS

The fruit wall or *pericarp* serves to protect the developing seed and to provide a food supply for *non-endospermic* seeds such as peas and beans.

Fruits are also the means of dispersing the seeds. Dispersal is summarised in Table 15.3.

The structure of fruits varies considerably. Some are *succulent* and juicy, and others are *dry* and able to split or not split open when ripe (Fig. 15.16). Table 15.4 outlines the classification of fruits.

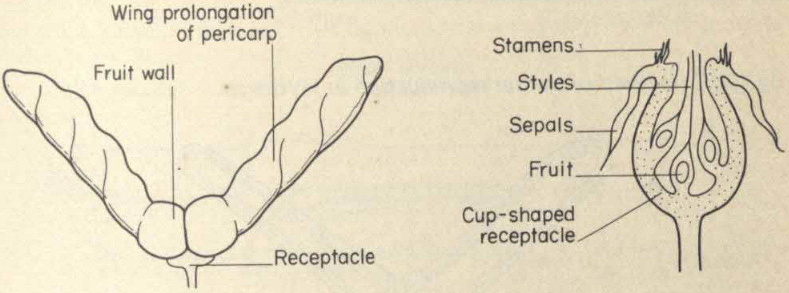
Table 15.3 *dispersal methods of fruits and seeds*

Dispersal method	*Features and example*
Mechanical dispersion	Stresses develop within *drying* fruits, shrinkage causes fruit to split open and sides curl back flinging out seeds. E.g. balsam, lupin, gorse and other pods
Wind dispersal	1 *Winged* fruits and seeds with aerofoil structure. E.g. sycamore, lime, ash, elm and pine 2 *Censer mechanism* for dry capsule fruits on long stalks. E.g. 'pepper pot', poppy, campion 3 *Parachute* fruits. E.g. dandelion, thistle and willowherb
Animal dispersal	1 *Hooked* fruits cling to animal coats. E.g. goosegrass, burdock and agrimony 2 *Succulent* fruits attract birds, seeds stick to feet, beaks, or pass through digestive tract and are distributed in faeces
Water dispersal	Water-resistant, air-filled fruit walls for buoyancy. E.g. coconut and water lily

Table 15.4 *classification of fruits*

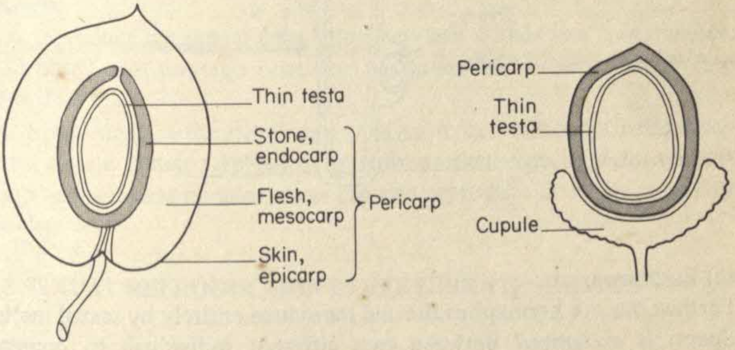
Fruit type	*Structure and example*
False fruits	Develop from the *receptacle* which becomes fleshy: apple and pear, strawberry and rose-hip
True fruits	Wall of fruit, *pericarp*, forms from ovary wall
1 *Succulent fruits*	Brightly coloured, one-seeded, fleshy fruits
Drupe	Seed enclosed by woody *stone*, with *flesh* and *skin*, forming the pericarp: plum, cherry, peach
Berry	Many-seeded, without stone, with surrounding flesh and skin of pericarp: orange, tomato, gooseberry
2 *Dry fruits*	Either *dehiscent*, split open, or *indehiscent*, do not open, when ripe
(a) Dehiscent	
Legume	Pod: bean, peas and lupins
Capsule	Box-like fruit: poppy, chestnut
(b) Indehiscent	
Nut	With woody wall: hazel, acorn
Achene	One-seeded fruit: buttercup. *True* fruit: strawberry and rose
Caryopsis	Grass and grain fruit with seed coat and fruit wall forming 'husk': oat, wheat, maize and grasses

fig 15.16 *examples of dry and succulent fruits: (a) sycamore,* Acer *sp., (b) rose hip,* Rosa *sp., (c) plum,* Prunus *sp., (d) oak acorn,* Quercus *sp.*



(a) Sycamore – dry indehiscent

(b) Rose hip – false fruit



(c) Plum – succulent drupe

(d) Oak – indehiscent nut

15.10 SEXUAL REPRODUCTION IN INVERTEBRATE ANIMALS

(a) *Paramecium*

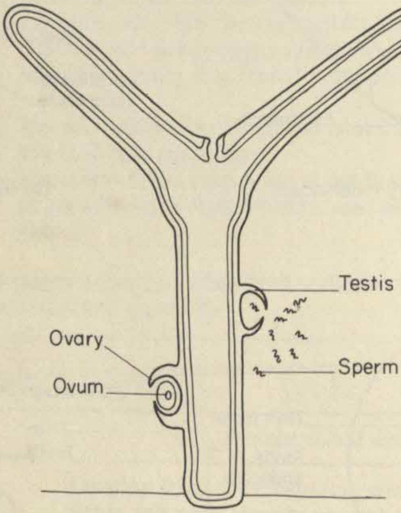
Two organisms meet with their oral grooves opposite. The surface membrane breaks down and they exchange *micronuclei*. After 16 to 18 h they separate and each cell divides into two by binary fission. This process occurs in times of food shortage.

(b) *Hydra*

Hydra is *hermaphrodite* in having gonads, ovary and testes, which mature at different times on the same individual. This prevents self-fertilisation.

Sperm are released into the surrounding water and are attracted to the ovary where fertilisation occurs *internally* to form a zygote (Fig. 15.17). The embryo is then released. It is surrounded by a protective chitinous shell and in this way survives adverse conditions.

fig 15.17 *method of sexual reproduction in* Hydra *sp.*



(c) Earthworm

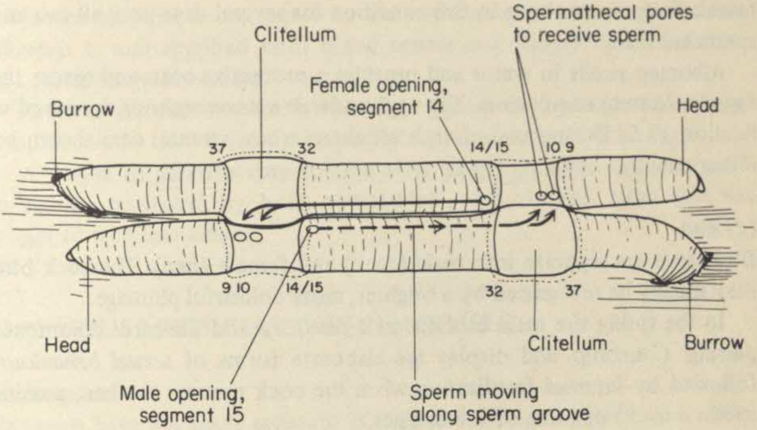
Earthworms are hermaphrodite and reproduce entirely by sexual methods. Sperm is *exchanged* between two different individuals by copulation (Fig. 15.18); this prevents self-fertilisation. The exchanged sperm is used to fertilise the ova *internally* and these are laid as eggs in a *cocoon*. The young develop directly into worms without a larval stage.

(d) Tapeworm

The tapeworm (see Figs 2.11 and 18.9) is hermaphrodite with the male gonads ripening before the female gonads, both of which are contained in the *same* ripe segment or *proglottid*. Self-fertilisation is therefore prevented.

Cross-fertilisation occurs *internally* between proglottids of *another* worm, or different proglottids on the *same individual*. The fertilised eggs are surrounded by a *shell* and almost fill the ripe segments at the end of the tapeworm body.

fig 15.18 *sperm exchange process occurring between copulating earthworms,* Lumbricus *sp.*



(e) Insects

Insects reproduce by sexual copulation between a male and female insect. The fertilised eggs undergo *complete* or *incomplete metamorphosis* (see Section 11.5).

Parthenogenesis is the development of an ovum *without* it being fertilised by a male gamete. Aphids or greenfly produce eggs by *mitosis* which develop into wingless females; these can also reproduce normally by sexual methods.

15.11 SEXUAL REPRODUCTION IN VERTEBRATE ANIMALS

(a) Fish

Fish, like most vertebrates, have *separate* sexes, male and female. Fertilisation in *bony fish* such as herring, salmon and trout is *external*. The eggs are small and are laid in great numbers into the surrounding water, where they are fertilised by sperm released over the eggs from the male. The fish *soft* roe are male testes, and *hard* roe the female ovaries.

The young fish feed on plankton and no *parental care* is shown by either parent except in the stickleback.

(b) Frog

The sexes are separate, female and male, the latter recognised by a *pad* on the forelimb first digit.

In spring the female becomes swollen with eggs, each with a food reserve of yolk and coat of albumen. Mating occurs in the water. The males show *sexual behaviour* in croaking to attract females. The male mounts the female's back and sheds sperm in a steady stream over the ova as they are laid. Fertilisation is therefore *external*. The male and female frogs move about in this condition for several days until all ova and sperm are shed.

Albumen swells in water and provides a protective coat, and spaces the eggs facilitating respiration. The eggs undergo *metamorphosis* described in Section 11.5. During metamorphosis there is *no* parental care shown by either parent.

(c) Bird

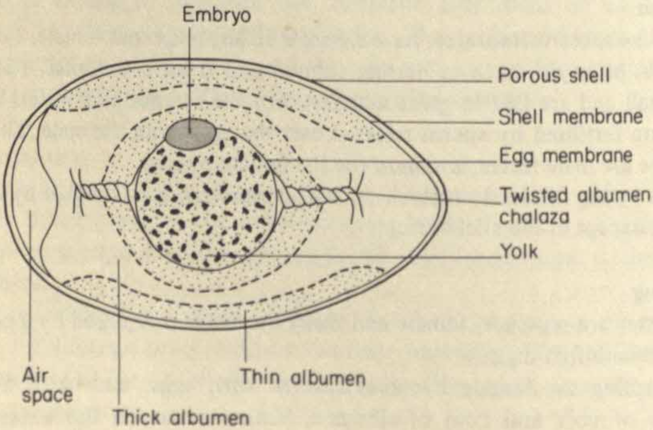
Bird sexes are separate into male (cock) and female (hen). The cock bird may usually be recognised by a brighter, more colourful plumage.

In the spring the male bird claims a *territory* and the birds commence pairing. *Courtship* and display are elaborate forms of *sexual behaviour*, followed by *internal* fertilisation when the cock mounts the hen, passing sperm into the opening of the oviduct.

Nest building involves the preparation of a structure made from different materials, or a simple structure composed of a few stones or a hollow in the ground.

A *few* eggs are laid, each egg (Fig. 15.19) composed of a central *yolk* food reserve with its *embryo* position in a *germinal disc*. Chalaza cords prevent rotation of the yolk *sac*. The egg white or albumen provides the developing embryo with water, and provides hydrostatic *support* and protection.

fig 15.19 *internal structure of a fertilised bird's egg*



The *shell* is porous, allowing gas exchange into the *air space* essential for the chick's respiration.

The young embryo becomes surrounded by an *amnion* or water-filled protective sac, and is connected to the yolk sac by an umbilical cord. The *allantois* is well supplied with blood vessels and functions in respiration and stores excretory waste.

After an *incubation* period when the eggs are maintained at a constant temperature by the hen bird, the young chick breaks out of the egg.

A period of *parental care* follows after hatching, when the young offspring are protected by both parent birds, and are fed. Later they are taught to feed themselves.

15.12 SEXUAL REPRODUCTION IN MAMMALS

(a) Structure

Mammals have the sexes separate in male and female individuals. Fertilisation in mammals is *internal*.

Development of the embryo can be within a soft-shelled egg, as in the platypus, or immature *live* offspring or embryos are produced which complete their development within a *marsupium* or pouch, as in the case of the *marsupial* mammals kangaroo and koala bear. Most mammal embryos develop within the mother's *uterus* and are protected and nourished by embryonic membranes and a *placenta*; such *placental* mammals are called *viviparous*, for example the rat, rabbit and human beings.

All young mammals feed on *milk* produced by the *mammary glands*. Mammals show considerable *parental care* of the young; this is seen in *feeding*, *protection* and *teaching* skills essential for their survival.

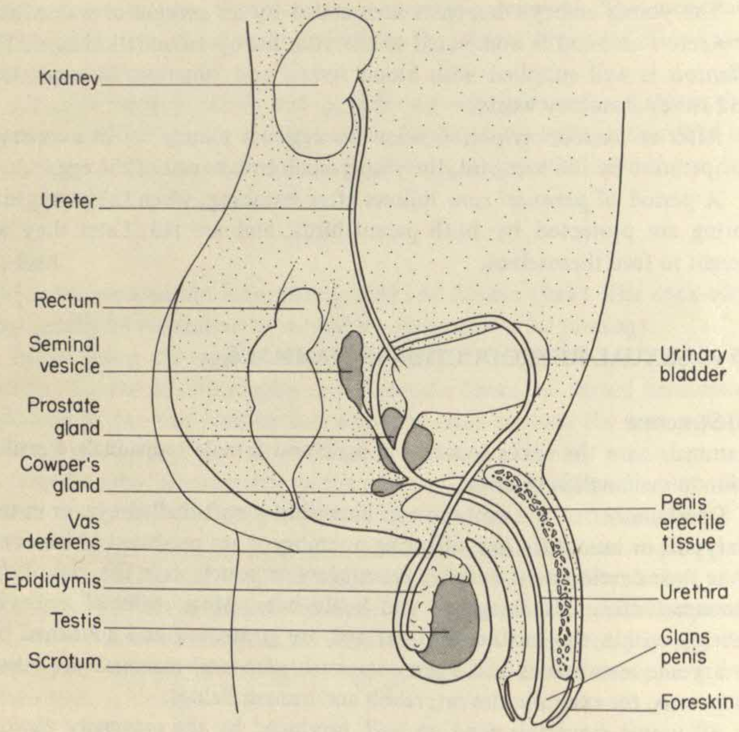
15.13 THE HUMAN REPRODUCTIVE SYSTEM

(a) The male

The male reproductive system is shown in Fig. 15.20. The *spermatozoa* are formed by spermatogenesis from cells lining the *seminiferous tubules* present as long coiled tubules within each testis, contained in a scrotal sac *outside* the body.

Each *spermatozoon* (Fig. 15.21a) consists of a *head* containing the nucleus of DNA material, and a short neck containing the energy-providing mitochondria, needed to propel the *tail*.

Sperm enter the *epididymis* and are temporarily stored there and also in the *vas deferens*. *Ejaculation*, or expulsion of sperm, occurs when the sperm is forced into the *urethra* by a reflex muscular action during sexual excitefig 15.20 *the human male reproductive system*



ment during copulation. Between 90 and 600 million sperm are produced in 3 cm^3 of ejaculate or *semen*. This fluid contains alkali, sugars and proteins from the *seminal vesicles, Cowper's gland* and *prostate gland.*

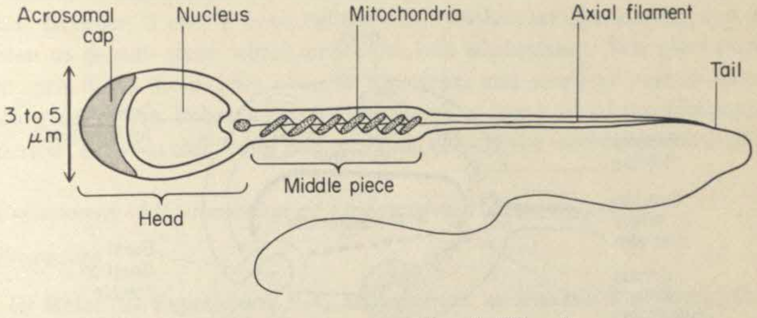
The *penis* becomes engorged with blood and is rigidly extended by its *hydrostatic* skeleton.

(b) The female

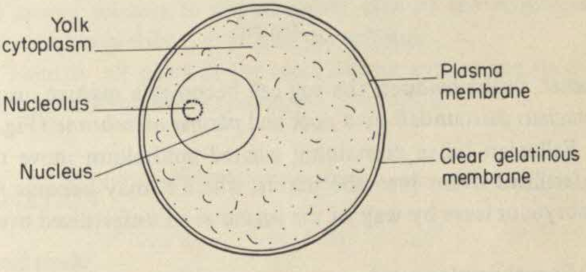
The female reproductive system is shown in Fig. 15.22. Two female *ovaries* lie within the abdominal cavity. Each ovary in a newborn female contains about 200 000 future ova, of which only about 400 will be released in a reproductive lifetime of about 30 years.

In a sexually mature female ovary, *one* egg cell (Fig. 15.23) develops each month within a fluid-filled *follicle* which bursts releasing the egg cell in a process of *ovulation.* The tissue left by the follicle becomes a yellow body or *corpus luteum.*

The egg cell falls into the body cavity and is collected by the *oviduct* fig 15.21 *the human (a) spermatozoon and (b) ovum (not to scale)*



(a) Spermatozoon (length 60 μm)



(b) Ovum (diameter 100 μm)

fig 15.22 *the human female reproductive system*

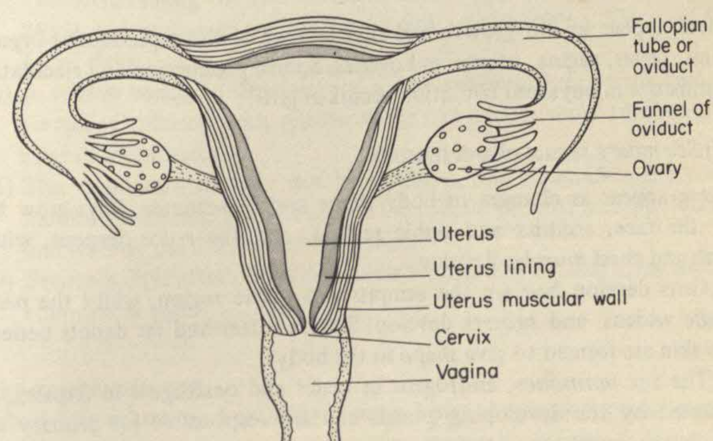
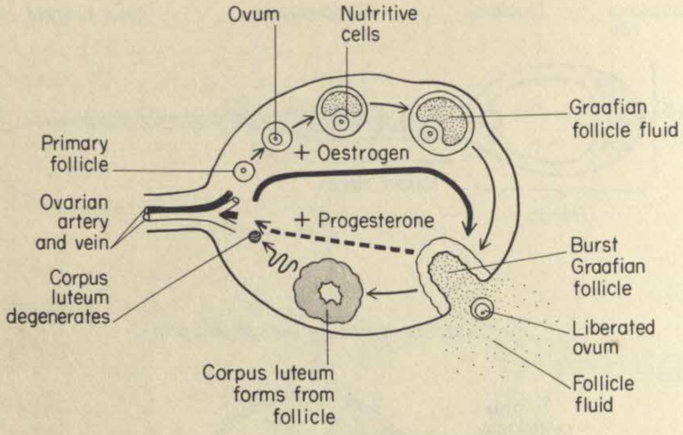


fig 15.23 *ovum formation stages in a human female ovary*



funnel. In the oviduct, the egg cell becomes a mature *ovum* consisting of a *nucleus* surrounded by a *yolk* and *plasma membrane* (Fig. 15.21b).

Fallopian tubes containing ciliated epithelium move the fertilised or unfertilised ovum into the uterus, where it may become *implanted* as an embryo, or leave by way of the *vagina* as an unfertilised ovum.

(c) Sexual development

Puberty is the stage of the *beginning* of sexual maturity. In girls it occurs between 12 and 15 years of age, in boys between 13 and 17 years.

(i) *Primary sexual characteristics*

These appear in the growth and enlargement of the reproductive *organs*, penis, testes, vagina, uterus and ovaries. Sperm production and ejaculation commence in boys and ovulation occurs in girls.

(ii) *Secondary sexual characteristics*

These appear as changes in body *shape* and *appearance*. Boys grow *hair* on the face, armpits and pubic regions, and the *voice* deepens, whilst limb and chest *muscles* develop.

Girls develop *hair* on the armpits and pubic region, whilst the *pelvic girdle* widens, and *breasts* develop. Skin is softer and fat depots beneath the skin are formed to give *shape* to the body.

The *sex hormones*, androgens in males and oestrogens in females, are secreted by the developing gonads and are responsible for primary and secondary sexual characteristics.

(iii) *Adolescence*

Puberty is that process of *maturing* of the reproductive organs which can last between 2 and 4 years. Apart from the sexual characteristics, it is seen as *growth spurt* which continues into adolescence. This spurt stops in girls when the ovaries become functional and stops in boys at about 20 years of age. Puberty can be considered as the start of the adolescent *period*, between childhood and *manhood* (13-25) or *womanhood* (12-21).

Experiment 15.2 *dissection of a mammal reproductive system*

Procedure

(i) Refer to Experiment 7.4, and proceed as described removing the entire gut.
(ii) Carefully probe and locate the *pubic* bone forming part of the pelvic girdle. Use strong scissors to cut on either side of the midline, and dissect away the bony tissue, to expose the urethra.
(iii) Trace and identify all parts of the reproductive system and its close connection with the excretory system.

15.14 FERTILISATION

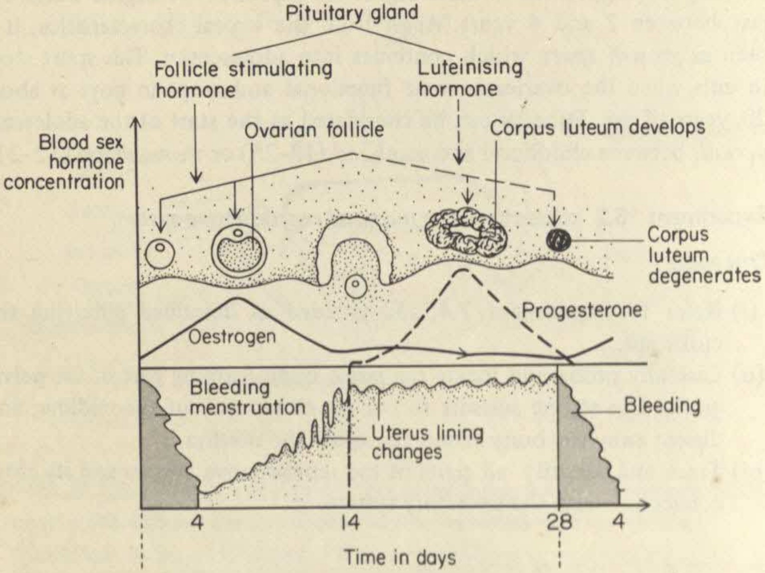
(a) The menstrual cycle

The menstrual cycle (Fig. 15.24) occurs in the sexually mature female and is seen as a shedding of the uterus *endometrium* lining together with a quantity of blood in the act of *menstruation*; this happens at the *commencement* of the menstrual cycle.

(i) The uterus lining the *endometrium* breaks up, and is discharged with blood and mucus as the *menses* by way of the vagina. This may last 5 to 7 days.
(ii) A follicle begins to develop, and a new endometrium uterus lining is formed. Ovulation with release of egg cell occurs some 14 days after start of menstruation.
(iii) The ovum may or may not be fertilised, and meanwhile the endometrium thickens. The remains of the follicle become a corpus luteum and secretes the hormone *progesterone*.
(iv) Fourteen days after ovulation, unless fertilisation occurs, menstruation commences again.

(b) Sexual intercourse

Sexual intercourse or copulation occurs when the erect penis is inserted into the vagina, and the sperm containing semen is ejaculated. The sperm fig 15.24 *summary of changes occurring in the female menstruation cycle*



pass partly by *swimming* and partly by the *peristalsis* of the female reproductive organs to reach the ova in the *oviduct*.

The acrosome or tip of the spermatozoa head digests the outer membranes of the ova and the sperm nucleus joins with the female nucleus to form a *diploid zygote*. No further sperm enter the fertilised egg cell due to the formation of an impenetrable *fertilisation membrane* (Section 16.6).

An egg cell or ovum is only present in the oviducts for a few days after *ovulation*. It is therefore necessary for sperm to be in the oviduct immediately before and during this period. Sperm can remain alive in the oviduct for up to 3 days after intercourse.

15.15 BIRTH CONTROL

The following are methods or birth control or *contraception* in order of *decreasing* efficiency.

(i) *Oral contraceptive pill* is a mixture of hormones, *oestrogen* and *progesterone*. These two hormones are produced during the menstrual cycle. When taken as tablets over 21 days they *prevent* ovulation.

(ii) *Intra-uterine device* (or IUD) is a metal or plastic strip or coil which is inserted *inside* the uterus. Its action is not understood, but its presence may stimulate antibodies or white blood cells to attack the sperm.

(iii) *Sheath and cap* are used in conjunction with a sperm-killing *spermicide* cream. Both are made of thin rubber surrounding the penis, or covering the uterus *cervix*, and act as a physical barrier.

(iv) *Unreliable methods* include using spermicides alone or intercourse outside the ovulation period.

(a) Sterilisation methods

(i) *Vasectomy* is an operation severing, parting and tying the vas deferens. Penile erection and ejaculation of *sterile* semen continue after the operation but there are no sperm in the semen.

(ii) *Oviducts* are cut, parted and tied, or the oviducal tubes are removed. It has no effect on the menstrual cycle.

15.16 DEVELOPMENT AND PREGNANCY

The fertilised egg or zygote becomes *implanted* in the endometrium of the uterus wall. The menstrual cycle stops, no further follicles develop and the corpus luteum becomes an important gland producing the hormone *progesterone*.

The zygote nucleus proceeds to divide by *mitosis*, to form two, then four and ultimately a ball of cells in a *blastula*. If the two first-formed cells part they develop into *identical twins*. If *two ova* are fertilised together, they form *fraternal* twins. The blastula develops into two main structures the *embryo* and its *placenta*.

The *placenta* forms a close association between the embryo and the mother's tissues. Numerous *villi* with blood capillary vessels project into blood-filled spaces provided from the mother's blood. The great number of villi increase the *surface area* for exchange of substances by diffusion to and from the blood spaces.

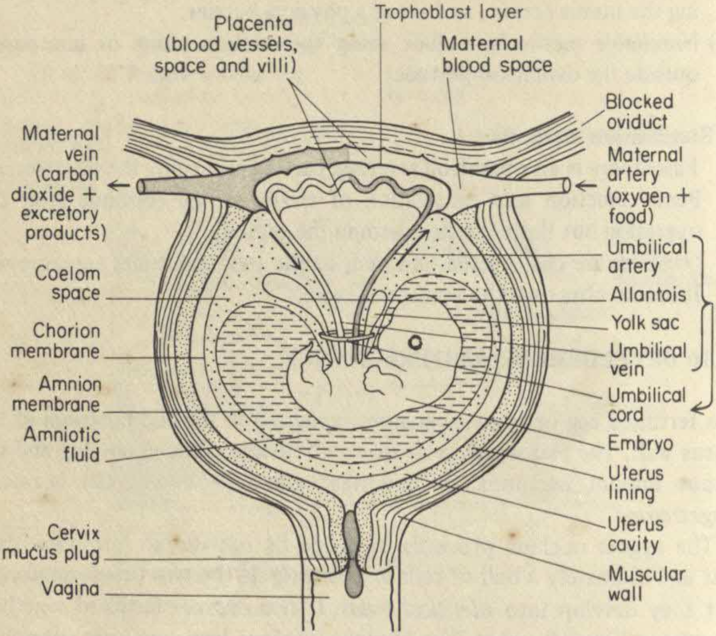
Food *nutrients*, protective *antibodies* and water pass from the blood space into the villi, whilst the special form of haemoglobin in the embryo draws up oxygen rapidly from the blood spaces. Waste carbamide (urea) and carbon dioxide diffuse *into* the blood space for removal in the mother's circulation.

The placenta acts as a gland in producing *hormones*, called *gonadotrophins*, oestrogen and progesterone, all of which control pregnancy.

After two months the human embryo (Fig. 15.25) is called a *foetus*, and is surrounded by a shock-absorbing *amniotic fluid* and amnion membrane. The foetus has a blood system and its *heart* pumps blood to the placenta by way of the umbilical artery in the *umbilical cord*.

Abortion is the termination of a pregnancy before the 28th week. Abortion is *legal* in certain countries when performed by qualified surgeons, but is a *criminal abortion* if performed otherwise. *Miscarriage* is accidental abortion due to several natural causes.

fig 15.25 *the human embryo in the uterus*



15.17 BIRTH

The act of birth is called *parturition*, and occurs nine months after fertilisation; the period of time is *gestation.*

Hormonal changes occur in the mother's blood system which involve an increase in the *oestrogen* level leading to contraction of the strong uterus wall muscles. Progesterone prevents this occurring during pregnancy.

Oxytocin, a hormone secreted by the pituitary gland, causes uterus wall muscle contraction, which happens at regular intervals in 'labour'. The uterus cervix dilates, and the amnion bursts releasing the amniotic fluid or 'waters'.

The baby is usually born head first and commences breathing unaided within a few seconds. Following the birth the placenta is expelled as the 'afterbirth'; the 'caul' is sometimes seen on a baby's head and is the remains of the *amnion*.

The mammary glands are stimulated to produce milk by the hormone *prolactin* from the pituitary gland. The normal menstrual cycle recommences after birth.

Table 15.5 summarises the important sex hormones and their functions in women.

Table 15.5 *sex hormones and their function in woman*

Gland or source	*Hormones*	*Functions*
Pituitary (brain)	FSH: follicle-stimulating hormone	1 Causes ovary follicles to develop 2 Stimulates ovary to secrete oestrogen
	LH: luteinising hormone	1 Causes ovulation – egg release 2 Causes *corpus luteum* to form from follicle 3 Stimulates progesterone secretion
	Prolactin	In *pregnancy*, promotes milk formation and secretion
	Oxytocin	1 Causes uterus to contract and birth of foetus 2 Causes milk flow
Ovary	Oestrogen	1 Causes uterus wall changes before ovulation 2 Secondary sexual characteristics, breast development, pubic hair
	Progesterone (corpus luteum)	1 Causes uterus wall changes *after* ovulation 2 Inhibits oxytocin
Placenta	Gonadotrophins, oestrogen, progesterone	1 Maintain the corpus luteum function 2 Maintain pregnancy

15.18 PARENTAL CARE

T The young baby is suckled on *milk* (see Table 8.1, composition of milk s milk), and gradually *weaned* onto a mixed *balanced* diet.

Protection in the home protects the young from harm, accident and disease. Small babies have a high surface area/volume *ratio* and can lose heat rapidly (see Section 12.12). This is partly overcome by heat-producing *brown* fat layers in the skin. The homeostatic heat control is not fully developed in the newborn child.

The long period of parental care seen in human beings involves teaching or *learning* from the *play*, *parents' example* and in *education* to acquire certain skills. Close bonds are established between parents and children.

15.19 QUESTIONS

1 Describe the structure of an insect-pollinated flower. Give an account of sexual reproduction in the flower, referring to pollination, fertilisation, seed and fruit formation.

2 Draw and describe an organ of perennation in a deciduous tree, and an organ of vegetative reproduction in a bulb-forming plant.

3 Draw and describe the female reproductive system of a mammal giving the function of each part. Describe how the embryo is protected, nourished and provided with oxygen during gestation.

4 State the main differences between sexual and asexual reproduction. Summarise *three* different methods of asexual reproduction in plants.

5 Briefly describe with named examples the following terms: (a) gametes; (b) spores; (c) hermaphrodite; (d) binary fission; (e) zygote.

CHAPTER 16

GENETICS

16.1 INTRODUCTION

Genetics is the study of resemblances and differences between related organisms caused by *inborn* or *genetic* and *environmental* effects.

The resemblances or differences are called *characters* or *traits*. They are something *seen* in an individual, such as eye or flower colour, or something that can be *tested* for biochemically, such as blood groups in human beings.

An individual organism starts its life with one *nucleus*; this contains the *genetic material* received from one parent (asexually) or two parents (sexually).

During mitosis (Section 11.2) the *nuclear* and *genetic* materials are distributed equally to the product cells, the *chromosomes* being split lengthwise equally into two halves called *chromatids*. The essential 'instructions' for an individual's characters, inherited from the parents, are transmitted to all body cells in the individual by mitosis of cell nuclei.

16.2 PHENOTYPE

The phenotype is a term describing the *actual* organism with respect to its *external* structural *form*, and its *internal* physiology or *function*. The phenotype is the total of all the *characters* that the organism shows. The resemblances and differences in characters are the means of classifying organisms into a *species* as described in Section 2.4. Members of a species will share certain characters resulting in their mutual resemblance, and these will be *inherited* by their offspring.

There will be differences between members of the *same* species; this difference within a species is called *variation*, and may or may not be passed on to the offspring (Section 16.13).

16.3 GENETIC MATERIAL – THE CHROMOSOMES

Thomas H. Morgan (1866–1945) was the first to investigate the structure and function of chromosomes by research on the fruit fly, *Drosophila melanogaster*.

Chromosomes (already described in Section 11.2) are only visible when a cell nucleus is about to divide.

Photographs of the dividing cell nucleus can be taken through a high-powered light microscope; these photographs are called *photomicrographs.* Plate 16.1 shows a photomicrograph of chromosomes from a specially treated human white blood cell nucleus, which is being used to construct a *karyotype* by artificially arranging similar size and shaped chromosomes on a chart.

(a) Chromosome number

Each chromosome is clearly visible in the karyogram and can be counted. Every body cell nucleus will have the *same* number of chromosomes; this is constant for a *species* of organism. Man has 46 chromosomes, a tobacco plant has 48, garden pea has 14 and *Drosophila* fruit fly has 8. There are *exceptions* where certain individuals *within* a species may have a different chromosome number.

(b) Homologous chromosomes

The *karyotype* or chart (see Plate 16.2) shows that in human *body* cell nuclei the chromosomes can be arranged in *pairs*, each similar in size and shape. These identical chromosome pairs are called *homologous chromosomes.*

(c) Autosomes and sex chromosomes

The karyotype of a human body cell nucleus shows that the 44 homologous chromosomes can be paired together as *autosomes*, whilst two chromosomes are called *sex* chromosomes (Fig. 16.1) These sex chromosomes are called X and Y chromosomes. The XX *homologous* pair is usually found in females, whilst the XY chromosomes are usually found in males (Section 16.14). The *exceptions* are seen in the nuclei of birds and butterflies where XX, homologous pair, is in male body cell nuclei and XY in female nuclei.

The X chromosome of *human beings* is *not* the same size and shape as a Y chromosome, the X chromosome being much bigger than the Y.

A human body cell nucleus will therefore have 22 *pairs* of autosomes, and *one pair* of sex chromosomes, making a total chromosome number of 46. A woman has 23 matched pairs of chromosomes, whilst the 23rd pair in a man *do not* match.

plate 16.1 *on the left is a photomicrograph showing the full set of chromosomes present in one human white blood cell nucleus. On the right is shown the chromosomes being grouped in homologous pairs (World Health Organisation)*

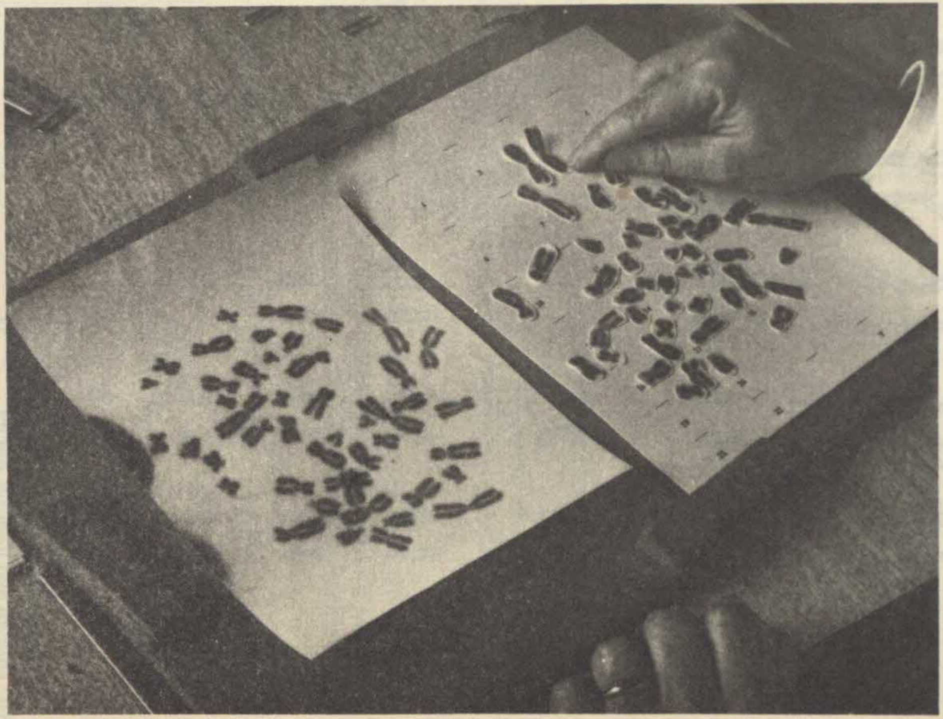
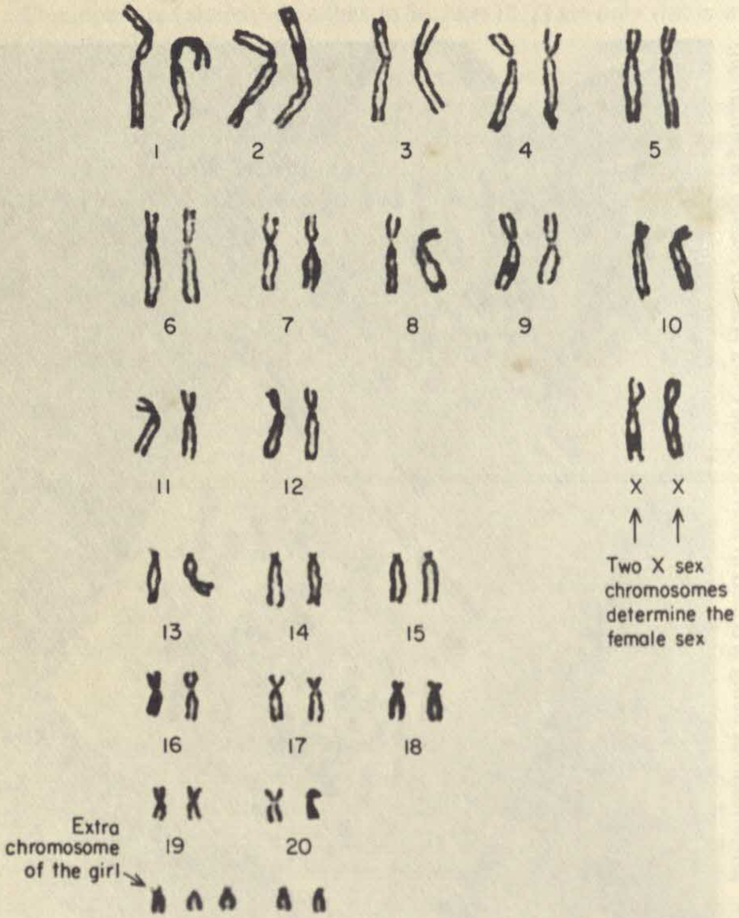


plate 16.2 *photomicrograph of chromosomes present in a cell nucleus of a girl with Down's syndrome. The* extra *chromosome is shown with the homologous pair number 21. Note the homologous paired XX chromosomes (Sandoz Ltd)*

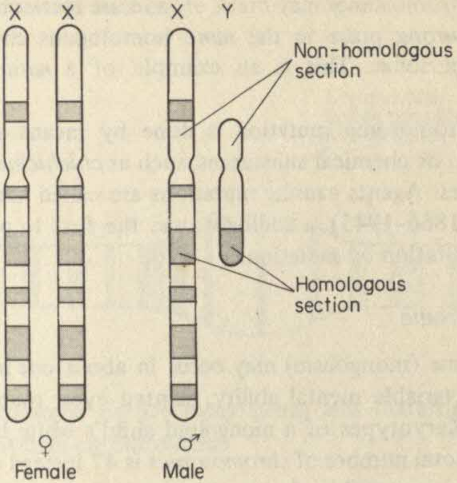

1
2
3
4
5
6
7
8
9
10
11
12
X X
Two X sex chromosomes determine the female sex
13
14
15
16
17
18
19
20
Extra chromosome of the girl
21
22

(d) Diploid and haploid nuclei

Diploid nuclei have the chromosomes in homologous *pairs* – seen in the *body* cell nuclei of animals and in *vegetative* cells of flowering plants.

Haploid nuclei have only one set of *unpaired* chromosomes – seen in the *gamete* cells and in *spores* of algae, fungi, liverworts and mosses. Gamete nuclei in human beings have 23 chromosomes, namely 22 autosomes and one sex chromosome.

fig 16.1 *sex chromosomes*



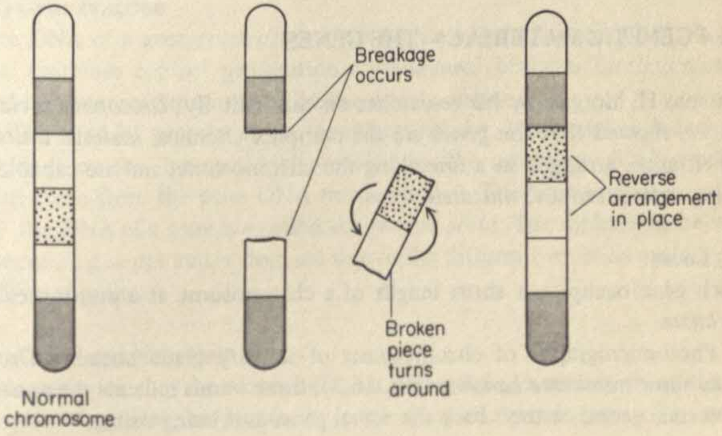
Haploid nuclei have *half* the chromosome number, or one set of chromosomes.

Diploid nuclei are given the symbol 2*n* (2 sets), and haploid nuclei *n* (one set). *Polyploid* nuclei can be 3*n* (3 sets), 4*n* (4 sets) etc.

(e) Chromosome mutations

Genetic material can be altered or changed by ***natural*** or ***artificial*** means, and so can cause sudden and permanent *changes* in a particular character. A change in chromosome structure or number is called a *mutation* (Fig. 16.2).

fig 16.2 *one method of chromosome mutation*



During the division of a nucleus by mitosis or *meiosis* (see Section 16.5) pieces of the chromosomes may break off and are lost or become attached again to the wrong place in the *same* homologous chromosome or a *different* chromosome. This is an example of a *natural* chromosome mutation.

Artificial chromosome mutation is done by means of radiation, for example X-rays, or chemical substances, such as *colchicine* extracted from autumn crocuses. Agents causing mutations are called *mutagens.* Thomas Hunt Morgan (1866–1945), a zoologist, was the first to perform artificial chromosome mutation by radiation.

(i) *Down's syndrome*

Down's syndrome (mongolism) may occur in about one in 1500 children, and is seen as variable mental ability, slanted eyes, round flat face and short stature. Karyotypes of a mongoloid child's white blood cell nuclei show that the total number of *chromosomes* is 47 instead of 46. The *extra chromosome* is responsible for an increase of the *total* chromosome number to 47 (Plate 16.2).

It is believed that one in every 100 human embryos has an *abnormal* chromosome structure. Many of these affected embryos are *spontaneously aborted* or miscarried.

(ii) *Polyploids*

Polyploids are cultivated *plants*, such as tomatoes, marigolds, wallflowers, raspberries and wheat, which have *extra sets* of chromosomes. This gives the organism certain advantages in producing showy flowers or increased crop yields. Polyploid plants are produced by treating seedlings and cuttings with colchicine.

16.4 GENETIC MATERIAL – THE GENES

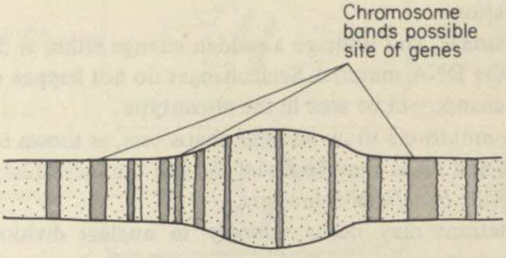
Thomas H. Morgan by his researches on the fruit fly, *Drosophila melanogaster*, showed that the *genes* are the complex chemical material *units* of inheritance, arranged in a *line* along the chromosome, and are capable of being *reproduced* and *mutated*.

(a) Locus

Each gene occupies a short length of a chromosome at a position called its *locus.*

Photomicrographs of chromosomes of salivary gland nuclei of *Drosophila* show *transverse banding* (Fig. 16.3); these bands indicate the *position* of certain genes, or their loci, the actual genes not being visible.

fig 16.3 *part of a large fruit fly,* Drosophila *sp., salivary gland chromosome showing banding*



Every chromosome carries *many* genes and therefore organisms will have more genes than chromosomes.

(b) Alleles

Homologous chromosomes when paired together will have similar genes or different genes called *alleles* on the same relative position or locus. An allele is an *alternative* form of a gene, controlling the *same* character but producing a *different* effect.

(c) Composition

DNA is the main component of a gene, which can be *duplicated* or *replicated* by uncoiling of the double DNA coil. This occurs in chromosomes during cell growth (see Section 11.3), thus doubling the DNA content before the nucleus divides.

(d) Gene function

The DNA of a gene controls *protein* synthesis (see Section 11.3). A gene can therefore control production of *structural* proteins forming muscles and bones, or of *functional* proteins, mainly enzymes.

The kind of protein to be manufactured, i.e. *structural* or *functional*, depends on the 'instructions' provided by the messenger RNA which in turn come from the gene DNA in the nucleus. The 'instructions' provided by the DNA of a gene are called the *genetic code.* The differences between *species*, e.g. a cat and a dog, are due to the different proteins made by the different genes.

(e) Genes and characters

One gene pair may be responsible for determining a certain character, e.g. height of garden pea plants, by controlling the production of a certain protein. Often *many* gene pairs together are responsible for *one* character, e.g. height of human beings (see Section 16.14). The total gene composition in the nucleus of an individual is called its *genotype*.

(f) Gene mutations

A gene can *mutate*, and undergo a sudden change either in the *amount* or *structure* of the DNA material. Such changes do not happen often and the effect of the change will be *seen* in the phenotype.

Most gene mutations show *harmful* characters, as shown by the following examples, and some may be *lethal* and kill the individual; occasionally they may provide *beneficial* characters.

Gene mutations may occur *naturally* in nuclear division, when the nucleotide bases interchange positions, or *artificially* by means of different mutagens, which include X-rays, ultra-violet and atomic rays. High temperatures and sudden temperature changes are also known to cause gene mutations. Drugs and chemicals such as mustard gas, nitrous acid, alkali, LSD and even caffeine of coffee are believed to be *mutagenic.*

PKU (phenylketonuria) is caused by natural mutation of a gene which normally controls the production of an *enzyme* which changes the essential amino acid *phenylalanine* into *tyrosine*. When the gene is absent the enzyme is not produced and phenylalanine accumulates in body tissues of young children; this causes mental and physical disorders. All babies born in the UK have their blood tested to detect the condition. Diets are then provided with foods *low* in phenylalanine, which allows the child to develop normally.

16.5 MEIOSIS

Meiosis (Fig. 16.4) is the nuclear division usually occurring in reproductive organs resulting in *gamete* formation. A *diploid* nucleus divides by meiosis to form *four* daughter nuclei each of which is *haploid*. Meiosis causes the chromosome number to be *halved*.

Meiosis occurs in *vertebrate* animals during gametogenesis before the sperm and ova are formed; in *flowering plants* it occurs during the formation of pollen and ovules.

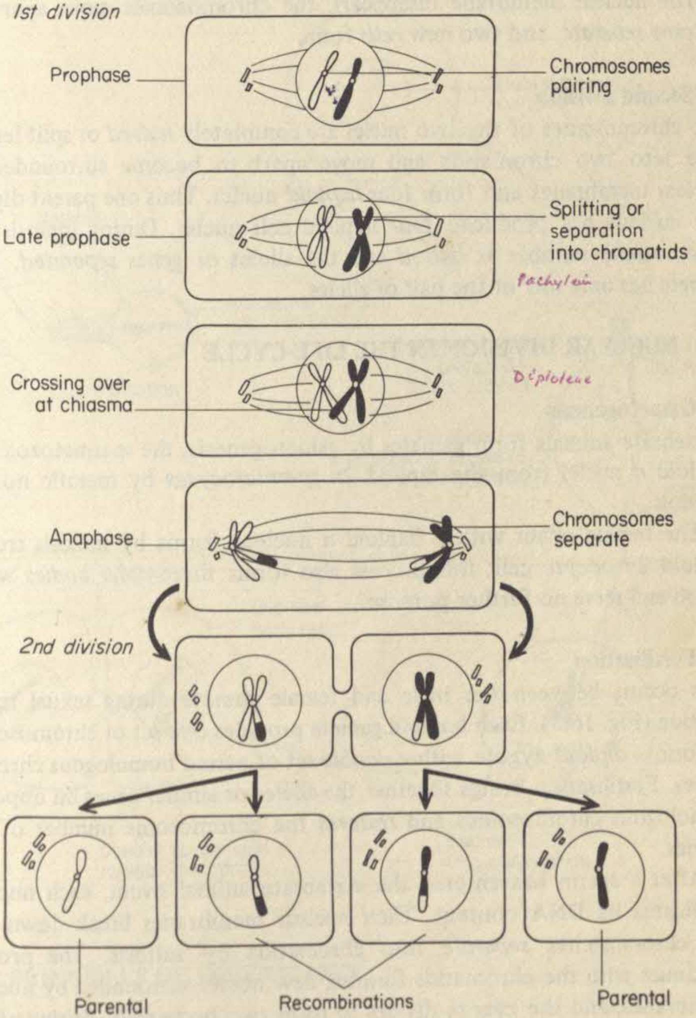
In man the chromosome number of diploid body cell nuclei is halved from 46 to 23 in the haploid gamete cell nuclei.

(a) Stages in meiosis

Meiosis is a more complex process that mitosis. Meiosis involves *two* successive nuclear divisions, after the process of duplicating chromosome material (see Section 11.3).

It is a *continuous* process described as taking place in up to 12 stages. The following is a summary of the main events.

fig 16.4 *the behaviour of chromosomes during nucleus division by meiosis*



(b) First division

Pairing and *separation*: homologous chromosomes come together in pairs with similar genes opposite each other. The previously duplicated chromosomes with double the DNA material form *chromatids*. During this pairing, some chromatids of homologous chromosomes *break* and *rejoin* at points called *chiasmata*. This causes *crossing over* with exchange of chromatid material between chromosomes from the parents; this will produce heritable *variation* in the offspring (Section 16.14).

The nuclear membrane disappears, the chromosomes move apart and become *separate*, and two new *cells* form.

(c) Second division

The chromosomes of the two nuclei are completely *halved* or split lengthwise into two chromatids and move apart to become surrounded by nuclear membranes and form four *haploid* nuclei. Thus one parent diploid cell nucleus has produced *four* haploid cell nuclei. During meiosis, the chromosome number is *halved* and the alleles or genes *separated*. Each gamete has only *one* of the pair of alleles.

16.6 NUCLEAR DIVISION IN THE LIFE-CYCLE

(a) Gametogenesis

Vertebrate animals form gametes by gametogenesis, the spermatozoa with haploid n nuclei from the diploid $2n$ *spermatocytes* by meiotic nuclear division.

The female ovum with a haploid n nucleus forms by meiosis from a diploid $2n$ *oocyte* cell; this process also forms three *polar bodies* which perish and serve no further purpose.

(b) Fertilisation

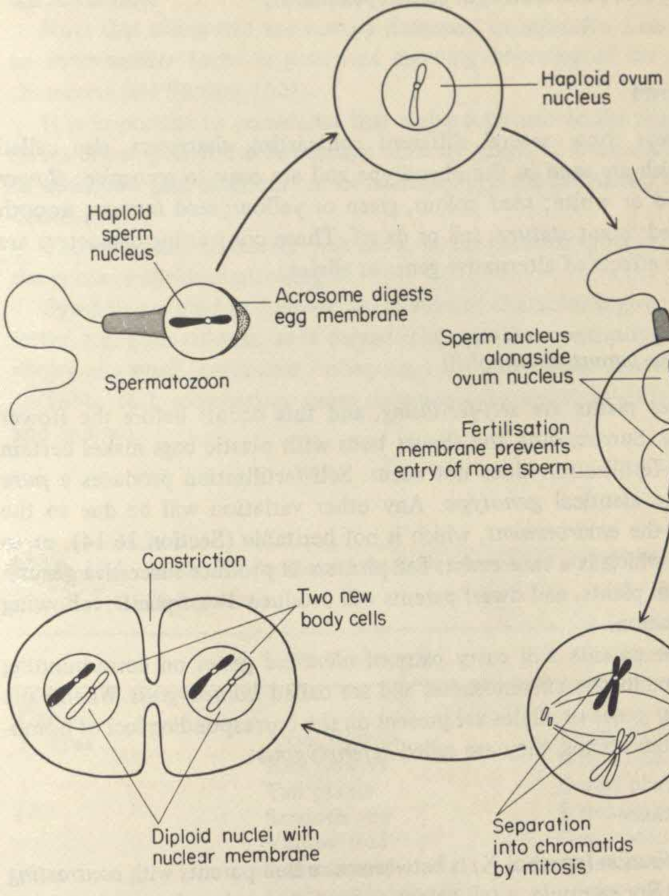
This occurs between the male and female gamete during sexual reproduction (Fig. 16.5). Each haploid gamete provides *one* set of chromosomes to form a *diploid* zygote with a *double* set of paired homologous chromosomes. Fertilisation brings together the alleles or similar genes on opposite homologous chromosomes and *restores* the chromosome number of the species.

After a sperm has entered the vertebrate animal ovum, each nucleus duplicates its DNA content. Their nuclear membranes break down and the chromosomes *separate* into chromatids by mitosis. The process continues with the chromatids forming new nuclei surrounded by nuclear membranes, and the zygote divides to form two body *cells. Pairing* of the chromosomes provided by either parent takes place at mitosis of the two body cells into four.

(c) Differentiation

The zygote nucleus proceeds to divide many times, producing the different *body* tissues of organs and systems. Later the *reproductive* cells form which must divide by meiosis to form the *haploid* gametes in order that the chromosome number of the species is maintained.

fig 16.5 ***schematic diagram showing fertilisation of vertebrate animal spermatozoon and ovum***


Haploid ovum nucleus
Haploid sperm nucleus
Acrosome digests egg membrane
Spermatozoon
Sperm nucleus alongside ovum nucleus
Fertilisation membrane prevents entry of more sperm
Constriction
Two new body cells
Diploid nuclei with nuclear membrane
Separation into chromatids by mitosis

16.7 PRINCIPLES OF INHERITANCE

Gregor Mendel (1822–1884), a priest, during the 1850s carried out breeding experiments using the garden pea plant; the result of his work provided an explanation of the basic *mechanism* of inheritance, or heredity.

Thomas H. Morgan founded the *chromosome theory* of heredity which explains that an individual's heredity is due to the *genes* received from its parents. Mendel called them *factors* and stated that these factors are transmitted to offspring, causing development of a particular *character*, or trait, to appear in the phenotype.

(a) Inheritance of contrasting characters

Mendel first studied the inheritance of *one* pair of *contrasting* characters, or *monohybrid inheritance*, in garden pea plants.

(i) *Characters*

Garden peas show several different contrasting characters, also called *traits*, which are *seen* in the phenotype and are easy to recognise: *flower* colour, red or white; *seed* colour, green or yellow; seed *texture*, smooth or wrinkled; plant *stature*, tall or dwarf. These contrasting characters are due to the effects of alternative genes or alleles.

(ii) *Pure-line parents (symbol P)*

Garden pea plants are *self-fertilising*, and this occurs before the flower buds open. Surrounding the flower buds with plastic bags makes certain that cross-fertilisation does not occur. Self-fertilisation produces a *pure line* of the identical *genotype*. Any other variation will be due to the effects of the *environment*, which is not heritable (Section 16.14), or to *mutation*, which is a rare event. Tall plants will produce successive generations of tall plants, and dwarf parents will produce dwarf plants, following self-fertilisation.

Pure-line parents will carry pairs of *identical* genes on corresponding loci of homologous chromosomes and are called *homozygous*. When pairs of *different* genes or alleles are present on the corresponding loci of homologous chromosomes, they are called *heterozygous*.

(iii) *Dominance*

Cross-fertilisation (symbol X) is between pure-line parents with *contrasting* characters. For example, a tall parent crossed with a dwarf parent produces all tall fertile *hybrids* in the first generation of offspring called the *first filial* generation (symbol F1).

Cross-fertilisation of garden pea plants does not occur naturally. It is achieved by artificial means by removing anthers from the flower while it it still in bud, called 'emasculation', and surrounding with plastic bags. When the flower opens it is pollinated with pollen of another plant using a camel-hair brush, and then enclosed in the bag.

Plants of the F1 generation show the *dominant character*: tall is dominant to dwarf, red is dominant to white flower colour, and yellow is dominant to green seed colour. This is due to the effect of *one* gene of the allele pair *suppressing* the effect of the other.

The F1 plants are *heterozygous* with different gene pairs, that is having a gene for tallness paired with a gene for dwarfness on homologous chromosomes.

Note that *characters* are usually dominant or recessive. Less commonly an *intermediate* form is produced showing *blending* of the contrasting characters (see Section 16.9).

It is important to remember that a character can be the product of the effect of *one* gene or the interaction of *many* genes. It is therefore incorrect to describe a gene as dominant or recessive. It is the *characters* which show dominance.

The dominant character will show in the *heterozygote*, as a result of the genes or alleles controlling it.

Symbols are used as follows: the dominant character is given the *capital* letter, e.g. T for tallness, or R for red. The recessive contrasting character is shown as a *small*, lower-case, letter, e.g. t for dwarf and r for white.

Table 16.1 summarises some dominant characters in different plants and animals.

Table 16.1 *some dominant and recessive characters or traits in plants and animals*

	Dominant	*Recessive*
Plants		
1 Peas	Axial flowers	Terminal flowers
	Red flowers	White flowers
	Tall plants	Dwarf plants
	Smooth pod	Wrinkled pod
	Yellow seed	Green seed
	Smooth seed, also called round	Wrinkled seed, also called shrunken
2 Maize	Yellow kernel	White kernel
Animals		
1 Cattle	Black cattle	Red cattle
	Hornless cattle	Horned cattle
2 Guinea pig	Black	White
	Rough coat	Smooth coat
3 *Drosophila*, fruit fly	Red eye	White eye
	Normal wing	Vestigial wing
	Normal body colour	Ebony body colour

(b) Gamete fusion and the Punnett square

The pure tall parent plant provides gametes containing the gene T, the pure dwarf parent plant provides gametes for the gene t. Using a 2 × 2 Punnett square, named after a geneticist, the outcome of cross-fertilisation and all the possible fusions of gametes can be shown.

Crossing X		*P tall gametes*	
		T	T
	t	Tt Heterozygous, tall	Tt Heterozygous, tall
P dwarf gametes			
	t	Tt Heterozygous, tall	Tt Heterozygous, tall

The *haploid* gametes carry one of the contrasting genes, T or t. Fertilisation produces *diploid* zygotes with the genes paired together as Tt, in a *heterozygous* plant. All the offspring show the *tall* character in the phenotype.

(c) Genotype and phenotype

The *pure* tall plants have the *genotype* or gene composition TT; the F1 hybrids have the genotype Tt. Both the pure tall and the F1 hybrid tall plants with *different* genotypes *show* the *same external* appearance in having the *same phenotype.*

The *pure* dwarf and the tall F1 hybrid have *different* phenotypes and *different* genotypes.

(d) Hybrid ratio

When F1 generation plants are allowed to *self-fertilise*, or animals interbreed between brothers and sisters, a *second filial generation* (symbol F2) is produced.

In the case of garden pea plants the flowers were enclosed in plastic bags to prevent cross-pollination.

The offspring seen in the F2 generation are a *mixture* or *assortment*. The F1 hybrid tall pea plant produces tall and dwarf plants. Out of a total F2 generation of 1064 plants, Mendel found 787 tall and 277 dwarf plants. This can be expressed as an *arithmetical ratio*: $787 \div 277 = 2.84$, or 2.84 tall plants to one dwarf; this approximates to a 3:1 ratio. This 3:1 ratio shows the ratio of *phenotypes*. The gene composition or *genotype* can be determined using the Punnett 2 × 2 square method.

The gametes of the F1 plants Tt are either T or t. This is displayed on the Punnett square to show all possible fusions of F1 gametes.

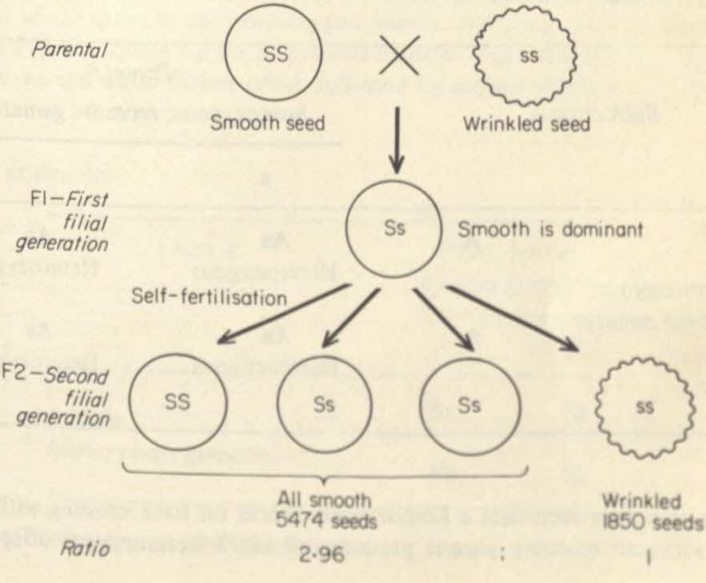
Selfing		*F1 hybrid tall.* *Gametes haploid*	
		T	t
F1 hybrid. *Gametes* *haploid*	T	**TT** Homozygous, tall	**Tt** Heterozygous, tall
	t	**Tt** Heterozygous, tall	**tt** Homozygous, dwarf

The *phenotypes* shown are 3 tall : 1 dwarf; i.e. TT, Tt, tT : tt. This shows that there is a 3 in 4 chance of F2 plants being tall, and a 1 in 4 chance of F2 plants being dwarf.

The *genotypes* are 1 homozygous pure tall (TT), 2 heterozygous hybrid tall (Tt or tT), 1 homozygous pure dwarf (tt). The *ratio* of *genotypes* is 1:2:1.

Fig. 16.6 shows the inheritance of seed coat texture.

fig 16.6 *the inheritance of a single character, that of seed coat texture in the garden pea,* Pisum sativum



(e) Law of segregation, or Mendel‘s first law

The characters of an organism are controlled by *genes* occurring in *pairs*, which retain their individuality from generation to generation. Only *one* of a pair of genes goes into each gamete, because they *segregate* or separate from others in *meiosis.*

16.8 THE BACK OR TEST CROSS

Two or more organisms may show the *same* phenotype, for example the red garden pea flowers may have *different* genotypes RR and Rr, and are homozygous and heterozygous respectively.

In order to *identify the genotype* it is necessary to perform a breeding experiment called a *back* or *test cross*. This involves crossing the *hybrid* with one of the *parents*. The parent chosen is the homozygous *recessive*, which is then cross-fertilised with the genotype to be identified.

The parent will have *one* type of gamete a; the genotypes to be identified, Aa and AA, will have two and one type of gamete respectively.

The Punnett squares are constructed as follows to show all possible gamete fusions.

(a) Homozygous hybrid AA back cross

Back cross X		*Parent:* *homozygous, recessive gametes*	
		a	a
Homozygous, hybrid gametes	A	Aa Heterozygous	Aa Heterozygous
	A	Aa Heterozygous	Aa Heterozygous

It is therefore seen that a homozygous *hybrid* on back crossing with the homozygous *recessive* parent produces *all* 100% heterozygous offspring.

(b) Heterozygous hybrid Aa back cross

Back cross X		*Parent:* *homozygous, recessive gametes*	
		a	a
Heterozygous, *hybrid gametes*	A	Aa Heterozygous	Aa Heterozygous
	a	aa Homozygous	aa Homozygous

It is therefore seen that a heterozygous *hybrid* on back crossing with homozygous *recessive* parent produces 50% heterozygous and 50% homozygous offspring.

16.9 INCOMPLETE DOMINANCE

A cross between a red Marvel of Peru flower pollinated by a white one gives seeds which grow into *pink* flowers in the F1 generation (Fig. 16.7). The self-fertilisation of these pink hybrids into an F2 generation produces a hybrid ratio of 1 red : 2 pink : 1 white flowers.

Incomplete dominance is seen in the phenotype of a heterozygote with characters blended and *intermediate* between those of either homozygote. Neither of the genes in the heterozygote exerts dominance over the other.

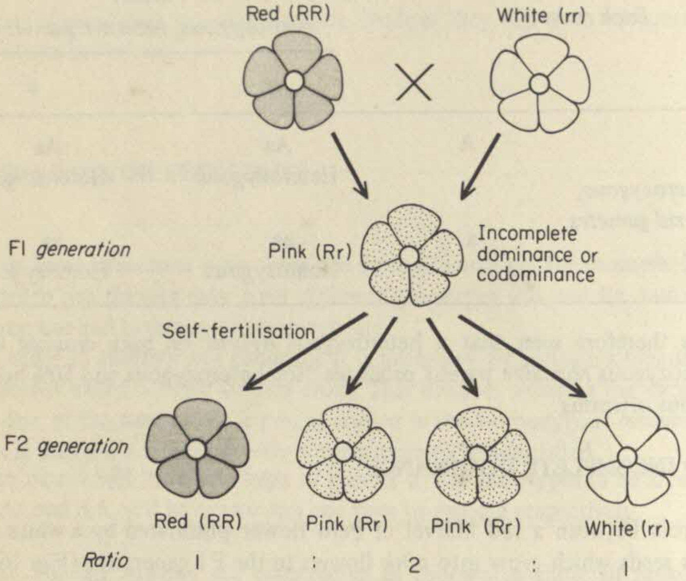
The Punnett square shows all possible fusions of gametes from a homozygous red and white flower *cross*, followed by *self-fertilisation* of the F1 generation.

(a) F1 generation

Cross X		*P red, homo-* *zygous gametes*	
		R	R
P white, *homozygous gametes*	r	Rr	Rr
	r	Rr	Rr

All are heterozygous *pink* phenotypes.

fig 16.7 *an example of partial or incomplete dominance, also called codominance, in the Marvel of Peru plant,* Mirabilis jalapa



(b) F2 generation

Self-fertilisation		*Pink, heterozygous, hybrid gametes*	
		R	r
Pink, heterozygous gametes	R	**RR** red Homozygous	**Rr** pink Heterozygous
	r	**Rr** pink Heterozygous	**rr** white Homozygous

The phenotypes are 1 red : 2 pink : 1 white. This shows there will be a 2 in 4 chance of flowers in F2 being pink, and 1 in 4 chance of flowers being red or white.

The genotypes are 1 homozygous red (RR), 2 heterozygous pink (Rr, rR), 1 homozygous white (rr).

Table 16.2 shows some examples of incomplete dominance found in plants and animals.

Table 16.2 *incomplete dominance in plants and animals*

Parents (homozygous)			*Offspring – F1 generation (heterozygous)*
Plants			
Round spherical radish	X	Long cylindical radish	Oval radish
Red flower snapdragon	X	White flower snapdragon	Pink flowered snapdragon
White flower Chinese primrose	X	Red flower Chinese primrose	Pink flowered Chinese primrose
Red flower Marvel of Peru*	X	White flower Marvel of Peru	Pink flowered Marvel of Peru
Animals			
Red Shorthorn cow	X	White Shorthorn bull	Roan (red and white haired) Shorthorn calves
Black Andalusian cockerel	X	White splashed Andalusian hen	Blue sheened Andalusian chickens

*Also called 4 o'clock flower as flower opens in late afternoon.

Experiment 16.1 *to demonstrate incomplete dominance*

Procedure

(i) Mix an exact equal number (200) of black and white beads. Divide into two equal lots. Place one lot in a box labelled 'sperm' and the other lot in a box labelled 'ova'.

(ii) Select, preferably blindfold, one 'gamete' from each box to pair in a 'zygote'.

(iii) Draw up three columns for combinations, headed BB, Bb and bb; let BB = black, bb = white and Bb = grey.

(iv) Continue the *random* pairing of beads or *genes* until all beads have been used in combinations.

Observations

Count each type of zygote and determine the hybrid ratio by dividing the smallest number into the other two numbers. A ratio approximating to 1:2:1 may be obtainable.

16.10 INHERITANCE OF HUMAN BLOOD GROUPS

Karl Landsteiner (1868–1943) discovered that the four human blood groups result from the influence of *three* genes called A, B and O. *Two* of these can pair producing the following combinations: AA, AO, BB, BO, AB, OO.

Genes A and B show *incomplete dominance* with respect to each other, because both genes express their effects equally. Both A and B genes are *dominant* over the O gene which is recessive.

Four main blood groups are detectable in human beings:

Group A due to AA or AO gene pairs
Group B due to BB or BO gene pairs
Group AB due to AB gene pairs
Group O due to OO gene pairs

Children will receive *one* gene from each parent. *Homozygous* AA, BB and OO groups form if the genes from both parents are the *same*. *Heterozygous* AB, AO and BO groups form if the parents provide *different* genes. The *six* different gene combinations form the *genotypes* of the *four phenotypes* in the four blood groups.

Blood group testing kits are available, for example the ‘Eldoncard’ for simple and rapid testing.

Inheritance of blood groups can be shown by means of the Punnett square method. This can be the means of deciding *paternity* of a child.

(i) *Example*

Male genotype AO, blood group A, has children by a female genotype BO, blood group B. Indicate the possible blood group genotypes of the children.

Cross X		*Male sperm*	
		A	O
Female ova	B	AB Group ‘AB’	BO Group ‘B’
	O	AO Group ‘A’	OO Group ‘O’

Table 16.3 *human blood groups*

Blood group (and percentage of UK population)	*Antigen substance on red cell membrane*	*Antibody substance in plasma*	*Genotype*		*Phenotype*	
A (UK, 40%)	A	Anti-B	AA AO	Homozygous Heterozygous	A	Dominant
B (UK, 10%)	B	Anti-A	BB BO	Homozygous Heterozygous	B	Dominant
AB (UK, 3%)	A *and* B	*No* antibody substance	AB	Heterozygous	AB	Incomplete dominance
O (UK, 47%)	*No* antigen substance	Both anti-A *and* anti-B	OO	Homozygous	O	Recessive

The male can only be the father of children with the blood group genotypes AB, BO, AO or OO. He will not be the father of any child with genotypes AA or BB, from the female of genotype BO.

(a) Blood compatibility

When blood from two different people is mixed, either *no* change occurs when the blood is *compatible*, or clumping or *agglutination* of red blood cells, together with bursting of the cells, *haemolysis*, occurs in *incompatible* blood.

Clumping of red blood cells is due to an *antigen* made by the red blood cell membrane reacting with an *antibody* in the other blood plasma.

In blood transfusion, only *compatible* blood can be used, since incompatible blood causes death.

The four blood groups differ by the presence or absence of the *antigens* A and B, due to different gene influence in making the particular functional *protein* on the red cell membrane. The groups are named according to whether antigen A or B is present or not.

Group AB can receive all other blood types and are *universal recipients*.

Group O can be given to all other blood types as a *universal donor*.

Table 16.3 gives a summary of the human blood groups.

16.11 SEX LINKAGE

This is the appearance of a certain character in *one* sex, namely the *male* mammal. The sex *chromosomes* are a homologous pair called X and Y concerned primarily with determining an individual's *sex* (see Section 16.3).

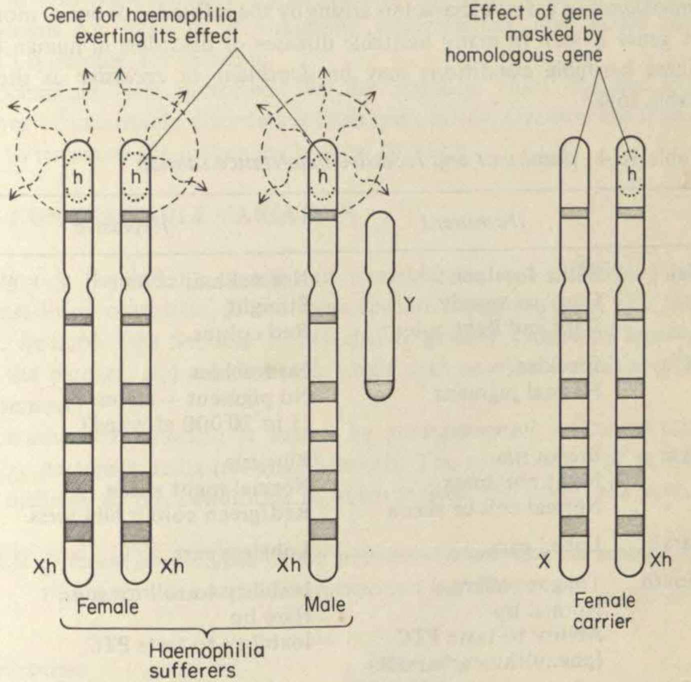
The X chromosome is longer than the Y chromosome in human beings, and the X chromosome carries *more* genes than a Y chromosome. The sex chromosome genes are not all concerned with sexuality.

Haemophilia is a heritable disorder of the blood characterised by slowness or complete inability to clot during bleeding. It is caused by a *recessive* gene on the X chromosome (Fig. 16.8).

The haemophilia gene can be shown by *, and is located at the end of the X chromosome shown as X*. In a X*Y male the gene * exerts its effect since it is unpaired. In a female X*X the gene is now paired and its effect is masked; the female is a *carrier* and a non-haemophiliac. Her sons can inherit the disorder from her.

If the female has a *double* dose of the haemophilia gene in the X*X* condition, she will be a *haemophiliac*. This is a very rare occurrence. Such females, if they survived birth, would be unlikely to survive their first menstruation.

fig 16.8 *bleeder's disease or haemophilia, showing the influence of the gene in sex linkage*


Gene for haemophilia exerting its effect
Effect of gene masked by homologous gene
h
h
h
h
Y
Xh
Xh
Xh
X
Xh
Female
Male
Female carrier
Haemophilia sufferers

Other sex-linked disorders include red/green colour blindness, Duchenne's muscular dystrophy, a muscle wasting disorder, and the inheritance of defective tooth enamel.

Punnet squares can be used to forecast haemophilia in children through marriage of a female carrier X*X with a normal male XY.

Cross X		*Male gametes*	
		X	Y
Female carrier gametes	X*	X*X Female carrier	X*Y Male haemophiliac
	X	XX Normal female	XY Normal male

The children of such a marriage can be normal males and females and carrier females, with haemophiliac males.

16.12 HUMAN HEREDITY

Inheritance of certain characters arising by the influence of one or more pairs of genes is seen in many heritable diseases or disorders in human beings. These heritable conditions may be *dominant* or *recessive* as shown in Table 16.4.

Table 16.4 *dominant and recessive inheritance in man*

	Dominant	*Recessive*
Hair	White forelock	Normal hair colour
	Curly or woolly	Straight
	Dark and light colour	Red colour
Skin	Freckles	No freckles
	Normal pigment	No pigment – *albinism* (1 in 20 000 affected)
Eyes	Brown iris	Blue iris
	Night blindness	Normal night vision
	Normal colour vision	Red/green colour blindness
Ears	Lobed ears	Lobeless ears
Mouth	Tongue rollers	Inability to roll tongue
	Normal lip	Hare lip
	Ability to taste PTC (phenylthiocarbamide)	Inability to taste PTC
Limbs	Extra fingers and toes – *polydactyly*	Normal number of fingers and toes
	Short fingers – *brachydactyly*	Normal finger length
	Short limbs – in *achondroplasia*, dwarfism	Normal limb length
Physiological	Resistance to tuberculosis (TB)	Lowered resistance to TB
	Ability to convert phenylalanine	*Phenylketonuria* (Section 16.4) (1 in 25 000 affected)
	Ability to decompose alkapton	*Alkaptonuria* (1 in a million affected)
	Normal mucus secretion in lung	*Cystic fibrosis* – abnormally thick mucus secretion in the lung, intestine and pancreas (1 in 2000 births)
	Huntington's chorea, progressive insanity and muscular spasm occurring in middle age (1 in 20 000 affected)	Normal condition

Amniocentesis is a technique for obtaining samples of *amniotic fluid* from around the foetus before its birth (see Section 15.16). This fluid contains cells from the foetus which can be examined microscopically by karyograms for signs of chromosome abnormalities that would cause Down's syndrome, for example.

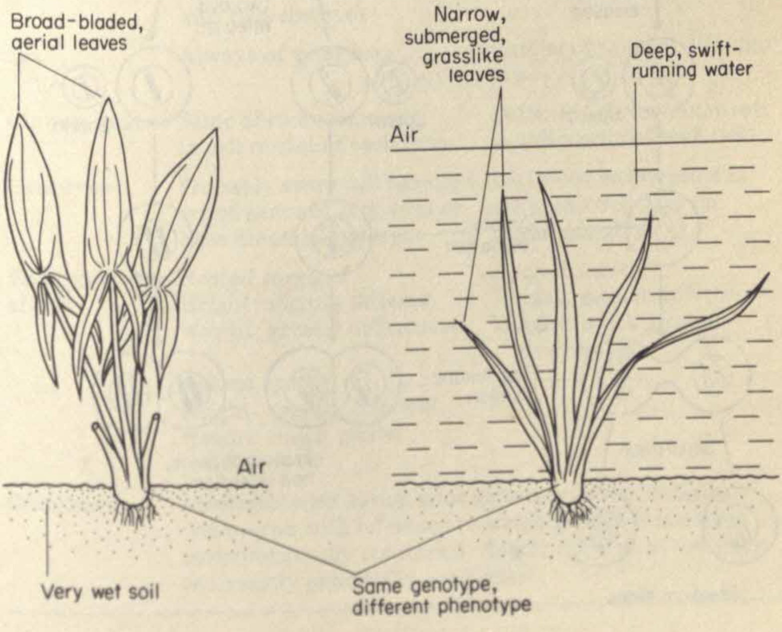
Biochemical tests performed on the amniotic fluid can also show evidence of inheritable disorders such as spina bifida. Decision can then be made to terminate the pregnancy by *legal abortion.*

16.13 NON-HERITABLE VARIATION

Variation is the infinite number of resemblances and differences seen amongst living organisms of the *same* species. Variation is of two main kinds: *heritable* (see Section 16.14), due to *genetic* characters inherited from the parents, and *non-heritable* (dealt with here), due mainly to the *environment.*

Non-inherited variation is caused by *environmental* influences other than by *mutagens*, radiation and chemicals. The *environment* of an organism includes all the conditions in which it lives; the body cells have an

fig 16.9 *different phenotypes of the arrowhead plant,* Sagittaria sagittifolia, *showing aerial and submerged leaf forms*

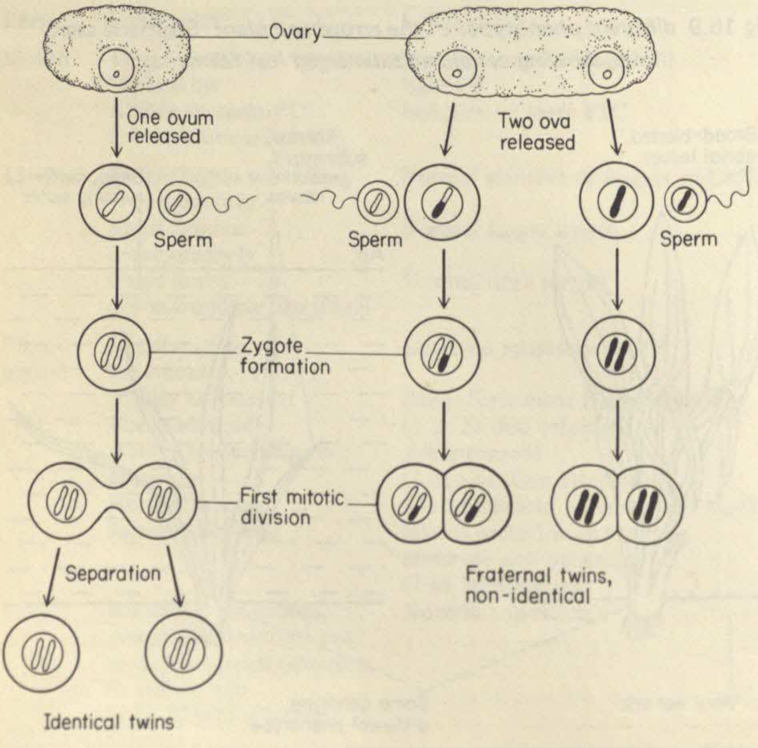

Broad-bladed, aerial leaves
Narrow, submerged, grasslike leaves
Deep, swift-running water
Air
Air
Very wet soil
Same genotype, different phenotype

internal environment due to tissue fluid of a *constant* composition, maintained in vertebrates by homeostasis (see Chapter 12). The *external environment* of an organism is of two kinds: (a) the *biotic factors* or external influences arising from the activities of other living plants and animals; and (b) the *abiotic or physical factors* due mainly to climate, temperature, light, wind, moisture, and also to mineral elements in sea water and soils (Chapter 18).

(a) The arrowhead plant

This shows two distinctly different *phenotypes*, depending on whether it is grown in deep running water when it develops long narrow grass-like leaves, or in wet soil when it develops broad arrowhead-shaped leaves (Fig. 16.9). Grown together in the same *constant environment* the offspring or daughter plants are indistinguishable from each other, showing the phenotype is due to environmental effects.

fig 16.10 *schematic diagram explaining the formation of identical and non-identical twins*



(b) Clones

These are organisms reproduced asexually from a single-celled plant or animal or vegetatively from a *single* multicellular plant. The descendants will all have the same genotype, unless mutation occurs.

A potato tuber can be cloned and reproduced by dividing one tuber into two parts. Each part if allowed to grow in *different environments*, such as a soil complete with mineral nutrients and a soil deficient in nutrients, will produce potato plants with *different* phenotypes. This shows that the variation is due entirely to the environment since the genotype is the *same* for both potato plants.

(c) Identical twins

Identical or *monozygotic* twins are the result of the division into two of the zygote derived from *one* fertilised ovum (Fig. 16.10). Such twins are genetically *identical* in having the *same* chromosomes and genes in their

Table 16.5 *comparison of identical and fraternal twins*

	Identical twins	*Fraternal twins*
Origin	Monozygotic: develop from *one* fertilised egg or zygote, which undergoes *fission* into two embryos	Dizygotic: develop from the simultaneous fertilisation of *two* separate eggs
Sex	Always of same sex	Can be of same or different sex
Chromosomes	Same chromosome sets in cell nuclei of each twin	Different chromosome sets in cell nuclei of each twin
Genotype	Probably every cell has same set of genes in each twin or have identical genotype	Different sets of genes in cells, and will have different genotype
Environmental effect	*Reared together* Height: slightly different Weight: greater differences	*Reared together* Height: greater differences Weight: much greater differences
	Reared apart Height: slightly different Weight: much greater differences	
Conclusion	Identical twins having same genotype, show differing phenotype with reference to *weight* which is mainly environmentally controlled. Height differences are slight and mainly genetically controlled.	

cell nuclei. They are members of the same *clone* and have the same *genotype.*

Fraternal or dizygotic twins result from the fertilisation of two separate ova. They *differ* genetically, having different chromosomes and genes like their brothers and sisters do. Table 16.5 compares identical and fraternal twins.

16.14 HERITABLE VARIATION

Dachshund puppies are bow-legged due to *genetic* causes; other breeds of puppies can be bow-legged due to *environmental* causes, a lack of vitamin D, causing *rickets*. Dachshunds will always inherit bow legs unless a mutation occurs which alters this character, whilst ricket-affected dogs of other breeds will *not* pass on rickets to their pups provided they are suitably fed.

Table 16.6 compares some heritable and non-heritable characters.

Heritable or genetic variations are of two main kinds.

Table 16.6 *comparison of heritable and non-heritable characters*

Heritable	*Non-heritable*
Genetic variations	*Environmental variations*
1 Due to genes	1 Due to environment, food, climate, soil, disease or other organisms
2 Reappears in offspring	2 Cannot appear in offspring
3 Mainly unchangeable in lifetime. Exception: curing of stomach outlet constriction (pyloric stenosis) by surgery.	3 Sometimes changeable in lifetime
Examples	
(a) Achondroplasia – dwarfs with short limbs	(a) 'Thalidomide' limb malformation
(b) Hereditary blindness and deafness	(b) Blindness and deafness due to syphilis or German measles in mother
(c) Bow-legged Dachshund puppies	(c) Bow-legged puppies due to rickets – vitamin D shortage
(d) Dwarf pea plants	(d) Stunted pea plants from *poor soil*
(e) Tall pea plants	(e) Etiolated pea plants grown in *poor light*
(f) Dark skin colour	(f) Sun-tanned, light skin colour

(a) Discontinuous or qualitative variations

This type of variation shows *sharp differences* amongst individuals of a *species*. It does not show any intermediate forms, the characters *contrast.*

Discontinuous variation (Fig. 16.12b) is caused by *one* or *two* genes which have a *major* effect and is mainly unchangeable during an organism's lifetime.

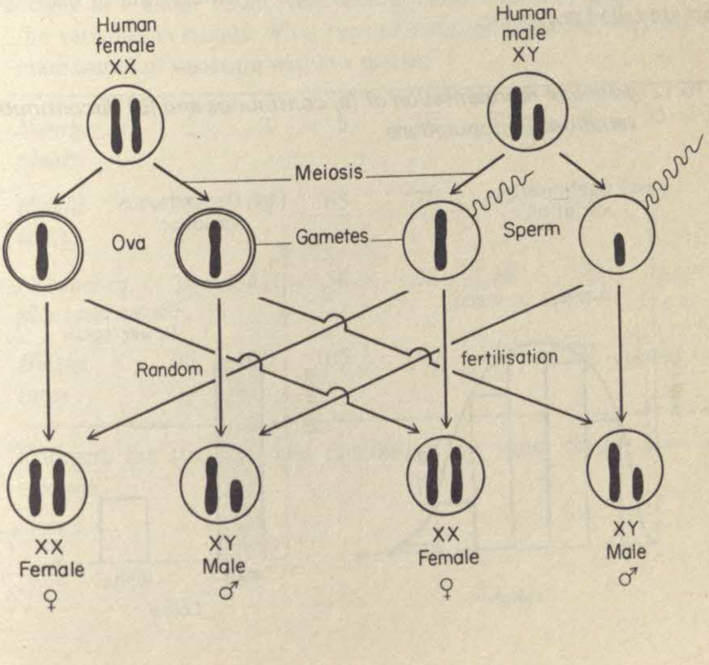
Discontinuous or qualitative variation is seen in human beings as the inheritance of *one* of the blood groups A, B, AB or O (Section 16.10) and of eye colour. Animals show discontinuous variation in the inheritance of a smooth or rough coat as in certain breeds of dog, e.g. Jack Russell, and pea plants are either tall or dwarf. The environment cannot affect this type of variation, since eye colour, blood group, skin and flower colour are all unchangeable.

Experiment 16.2 *to demonstrate sex determination* (Fig. 16.11)

Procedure

(i) Obtain two sets of black and white beads.
(ii) Place 100 black beads in one box and label as 'female ova'.

fig 16.11 *sex determination in mammals*



(iii) Place 50 black and 50 white beads well mixed together in another box and label 'male sperm'.
(iv) Blindfold a person and request they take one bead from each box to form a 'zygote'.
(v) Draw up in two columns one labelled XX (or black + black) 'female' and the other XY (or black + white) 'male'.
(vi) Pair *all* the beads from both boxes and record the 'combinations' produced.

Observations

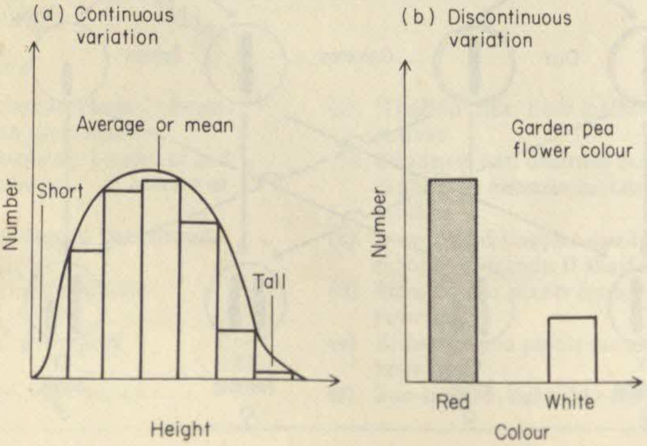
The sex chromosomes are described in Section 16.3. In fertilisation they meet and pair *randomly*. From the experimental results half the 'zygotes' are male XY and half are 'female' XX. This is *discontinuous variation* or qualitative inheritance of sex. In the United Kingdom, 6% more boys are *born* compared to girls each year. The ratio of females to males in the United Kingdom *population* is 105 females to 100 males. Evidently there is a higher mortality of men of all ages.

(b) Continuous or quantitative variations

This type of variation is seen as very *small* differences amongst individuals of the same species, and many *intermediate* forms are to be seen.

Continuous variation (Fig. 16.12a) is partly due to the effects of *many genes* of *small* effect. Characters controlled by interaction of many gene pairs are called *polygenic*.

fig 16.12 *graphical representation of (a) continuous and (b) discontinuous variations in populations*



Continuous or quantitative variation is seen in the wide *range* of values for *height* and intelligence quotients in human beings. This type of inheritance is caused by effects of polygenes *and* the environment, and is called *multifactorial inheritance*.

Continuous variations can be shown *graphically* and by frequency distribution histograms (Fig. 16.12).

16.15 QUESTIONS

1 What is the purpose of mitosis and meiosis? Describe the main differences (a) between mitosis and meiosis; and (b) between sex chromosomes and autosomes.

2 When a pure-line *red* flowered plant is crossed with a pure-line *white* flowered plant, all the seeds produce plants with red flowers. Explain what happens if these red flowered plants are (a) self-fertilised, and (b) back-crossed.

3 Explain the following terms in respect of human beings: (a) allele; (b) chromosome number; (c) genotype; (d) homozygous; (e) recessive character.

4 The following data show the *numbers* of barley plants having a certain *height* in a batch taken from a crop. Draw a suitable graph to show the variation in height. What type of variation is shown. What are the main causes of variation within a species?

Number of plants	2	3	5	10	13	9	25	30
Height (cm)	55	60	65	70	75	80	85	90
Number of plants	34	41	56	32	22	8	3	
Height (cm)	95	100	105	110	115	120	125	

5 Compare the structure and function of the gene, chromosome and nucleus.

CHAPTER 17

EVOLUTION

17.1 INTRODUCTION

The *Earth* is one of nine major planets revolving around the Sun, and is estimated to have come into being about 4750 to 5000 millions years ago. The first *living* organism emerged over 3000 million years ago, and *today* the Earth is inhabited by more than two million different *species*.

In this chapter the *origin* of the species is considered or how the present-day plants and animals came into being.

17.2 CHEMICAL EVOLUTION

Evolution is a process of gradual development from simpler forms through a series of changes.

Chemical evolution is one means of explaining the origin of *life* on Earth through the formation of complex organic compounds, like the DNA molecule, capable of reproducing themselves. The other alternative explanations include a supernatural origin of life, and the landing of 'life seeds' on Earth from some other planet.

Chemical evolution explains the formation of the complex organic compounds from simpler chemical elements or compounds. Alexander Ivanovich Oparin (*b.* 1894), a biochemist, first produced an account of the chemical origin of life.

S. Miller in 1953 passed electric discharges or electrical *energy* into a *mixture* of methane, CH_4, ammonia, NH_3, water, H_2O and hydrogen, H_2. The product was an *organic mixture* consisting of sugars, organic bases, fatty (alkanoic) acids and amino acids, all of which are important *biochemical* components of living organisms.

Biochemistry shows that living organisms are composed of similar organic compounds, in particular the *proteins* and *nucleic acids*. These could have been synthesised in conditions prevailing over 4000 million years ago on Earth, and formed by a process of chemical evolution into a DNA nucleic acid substance capable of replicating itself (see Sections 11.3 and 16.4).

A complex *organic mixture* would provide the essential *nutrients* and amino acids in a primitive *soup*. In this soup the first living *cells* may have been evolved as *virus-like* organisms able to function in an atmosphere without oxygen, that is *anaerobically*. Once a *living* organism had been formed from non-living organic compounds, more living things would arise by *biogenesis*. Living organisms may have had a common *ancestry* in the soup of organic materials.

17.3 EVIDENCE FOR ORGANIC EVOLUTION

Organic evolution is concerned with the evolution of populations of *living organisms*.

Organic evolution is a continuous and irreversible process of change in the *inheritable characters* of interbreeding organisms occurring through successive generations. The first bacteria-like organisms fed on a ready-made soup. Later it was necessary to *photosynthesise* food and a form of *algae* was evolved. These primitive algae produced food for themselves and others by photosynthesis and also produced *oxygen*, which accumulated in the air for the first time in the Earth's history.

Evidence for the existence of primitive algae, related to existing *blue-green* algae, was found as *microfossils* in South African rocks over 3000 million years old.

(a) Fossil evidence

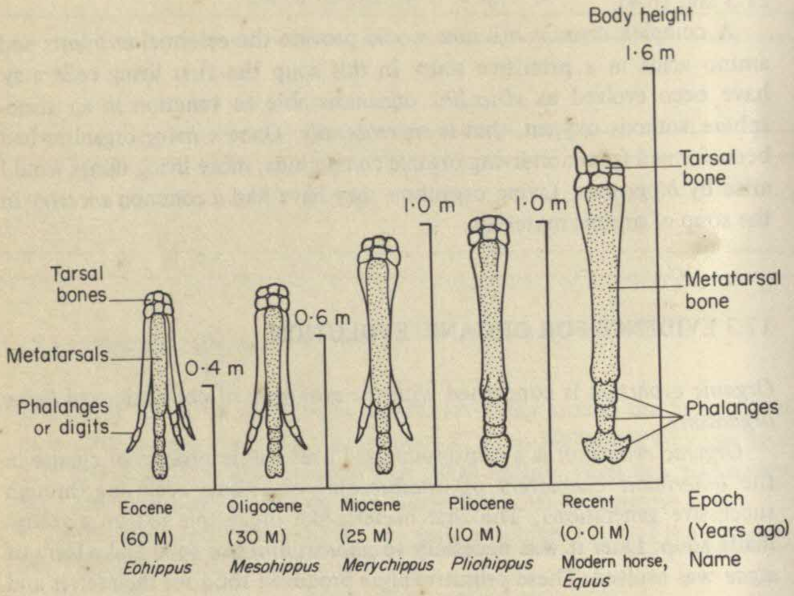
Fossils are either the actual remains or traces of organisms that lived in ancient geological times. The organism may be *embedded* in sand, resin or ice, or an *impression* or cast is made of body parts, the tissues being replaced or *petrified* by silica or calcium carbonate minerals.

Most fossils are found in *sedimentary* rock, sandstone and limestone, which forms as a settling and compacting of waterborne sediment, sand, silt, mud and animal shells.

Identical fossils are found in rock beds or strata *formations* laid down at the same geological time. These *index fossils* indicate the geological *age* of the rock formation. Rocks and fossils can also be dated by *radioactivity* measurement.

Fossil fuels include coal, oil and natural gas formed respectively from the remains of plants and minute shellfish or molluscs.

fig 17.1 *fossil record of hindleg bone evolution of the horse,* Equus *sp.*



A study of fossils can provide a *visual* record in a complete series showing the evolution of an organism, for example the horse (Fig. 17.1). Certain *link* fossils, for example *Archaeopteryx*, which was a bird-like animal with *teeth*, provide a link with the reptile ancestry of birds.

Microfossils are the oldest fossils of early microbe life which were the main kind of life until 500 M (million) years ago.

Fossil study or *palaeontology* shows that organic evolution was a gradual process spanning the last 3000 M years of Earth's history (Fig. 17.2). Evolutionary changes were not *linear* (in a straight line) but a *branching* process of descent from a common ancestor, seen in an evolutionary *tree*.

(b) Comparative anatomy evidence

The *pentadactyl limb* (see Section 14.3) was evolved as an adaptation to living on land and became the means to walk, run and fly. Pentadactyl limbs are *homologous organs* having the *same origin* in a common ancestor, but have developed *different functions* (Fig. 17.3).

An insect wing is an *analogous* organ having the *same function* as the wing of a bird and bat but with different *origin*.

fig 17.2 *fossil record of plants and animals shown in a geological time chart relating to the 'great ages' of different groups of organisms*

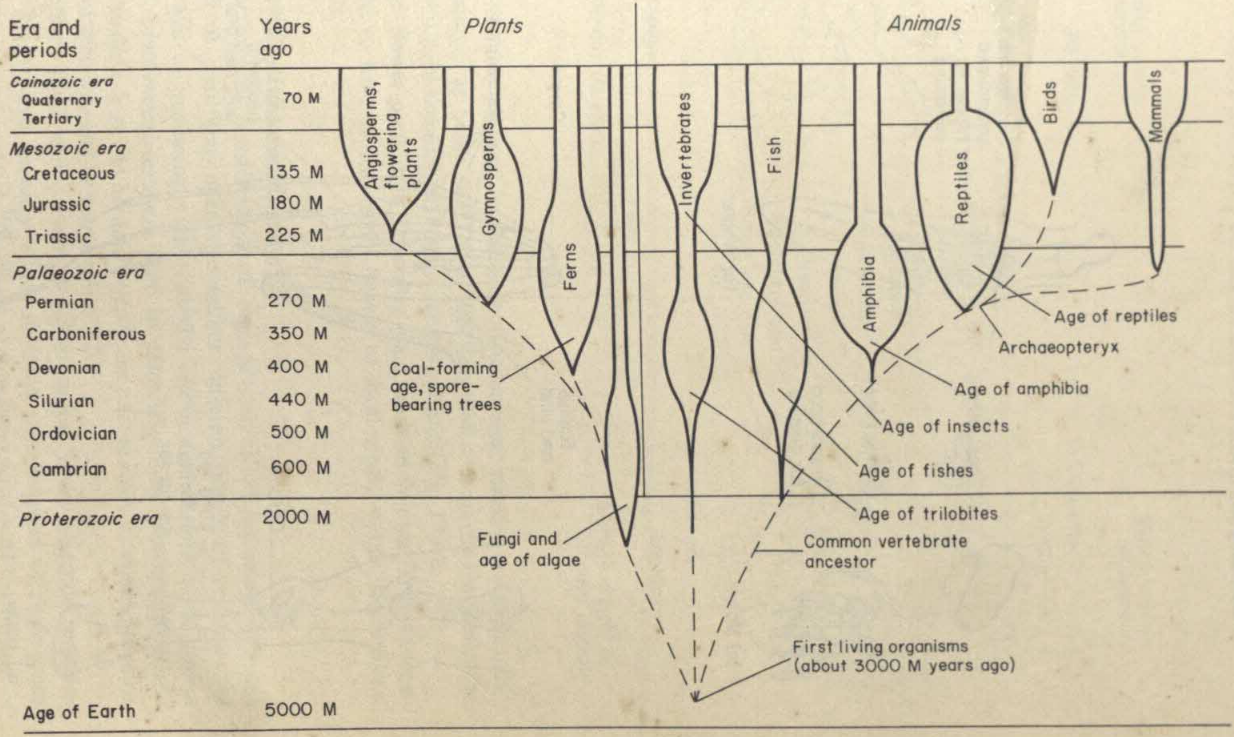
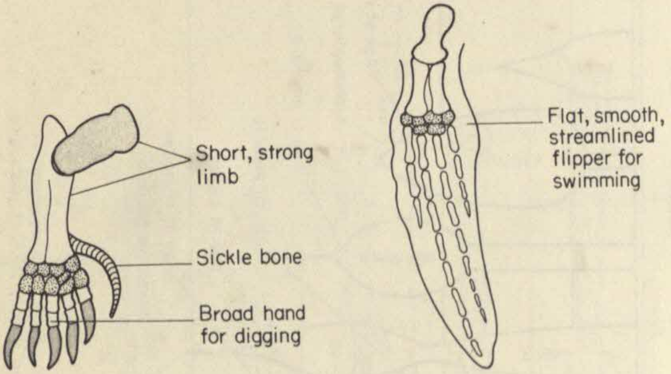
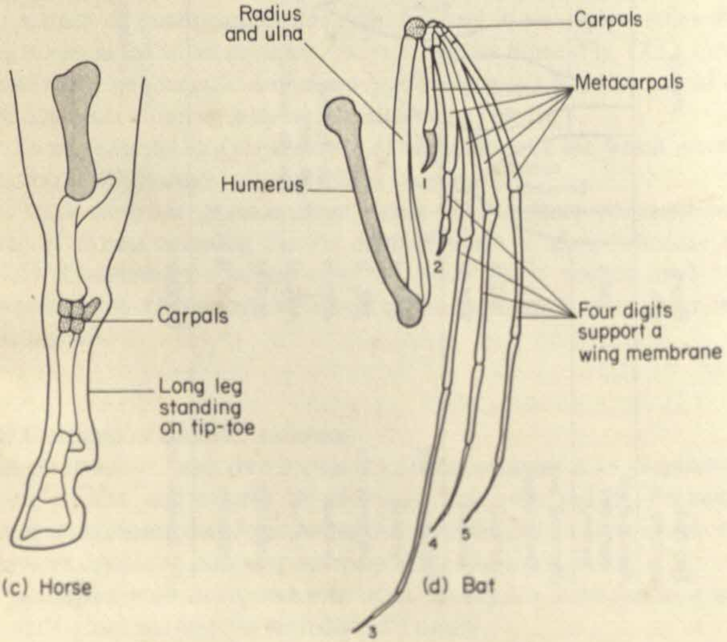


fig 17.3 *adaptation of vertebrate pentadactyl forelimb and examples of homologous limbs*



(a) Mole

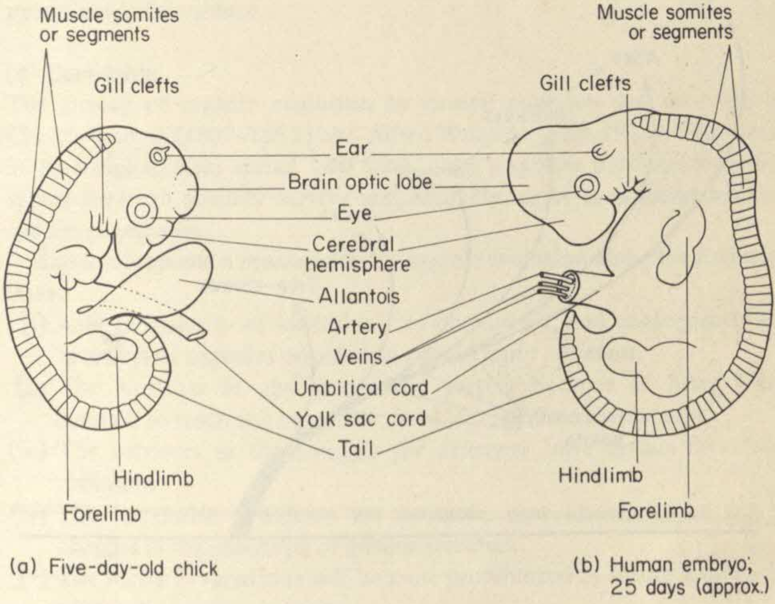
(b) Whale


Radius and ulna
Carpals
Metacarpals
Humerus
1
2
Four digits support a wing membrane
Carpals
Long leg standing on tip-toe
4
5
3

(c) Horse

(d) Bat

fig 17.4 *early embryos of (a) a bird and (b) man showing gill clefts, a feature of* all *early vertebrate embryos*



(a) Five-day-old chick

(b) Human embryo; 25 days (approx.)

Vertebrate embryos in the early development stages are almost indistinguishable as being that of a fish, amphibian, bird or mammal. The embryos have homologous organs seen as *gill* slits (Fig. 17.4).

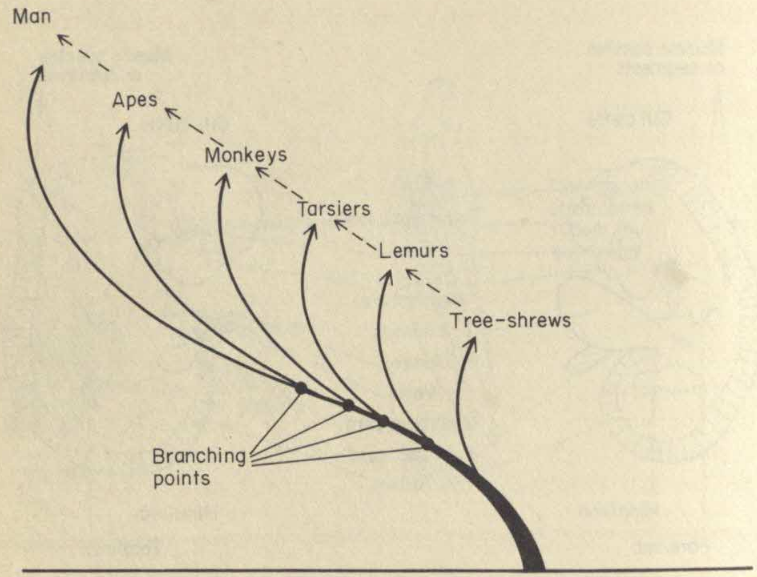
The flower parts of a flowering plant are homologous. They are considered to have evolved from *leaves*, to form sepals, petals, stamens and carpels.

(c) Evidence from classification

The science of classification of organisms is called *taxonomy* and is a means of classifying over two million different kinds of organisms on the basis of possessing certain similar *characters*. If differences appear slight, *biochemical* tests are used to determine close relationship. *Blood agglutination* tests can be used to indicate relationships between primates, e.g. chimpanzees and baboons (Fig. 17.5).

Extinct fossil and present *living* organisms when classified together show kinship and ancestry which indicates the closeness of their evolutionary descent, and the *divergent* or branching nature of the process of evolution.

fig 17.5 *classification of primates showing relationship by descent*



17.4 THEORIES OF EVOLUTION

(a) Special creation

All species had a *separate* origin without any relationship between the different species, and the species has remained *unchanged*. The account in the Book of Genesis was written over 4000 years ago.

(b) Lamarckism

Jean Baptiste Lamarck (1744-1829) put forward the theory of *acquired characters* as an attempt to explain the *mechanism* of organic evolution. The theory stated that all living organisms were related, and *variation* in the *phenotype* was developed due to 'use and disuse' of body parts, such changes being considered heritable. Fossil evidence shows that the ancestor of the giraffe had a short body and neck, the long neck having evolved from the habit of reaching for leaves higher up in the trees. This was disproved by cutting off the tails of breeding mice and finding the offspring born all had normal tails.

In Section 16.13 it is shown that variations due to the environment are *non-heritable*.

(c) Neo-Lamarckism

Supporters of this theory believe that environmental influences affect self-reproducing substances in the cell *cytoplasm* called *plasmagenes*. This gene-like substance is passed on to affect daughter cell characters by *cytoplasmic inheritance*.

(d) Darwinism

The theory of organic evolution by *natural selection* was proposed by Charles Darwin (1809-1882) and Alfred Wallace (1823-1913). This theory in its simplest form stated two facts: first, a species produces more offspring than can possibly *survive* and, secondly, there is *variation* within a species population.

Darwin proposed a *mechanism* for organic evolution along the following lines:

(i) A large majority of individuals *do not* survive, and consequently the numbers of a species population remain fairly *constant*.
(ii) The survivors in any population survive because of being better *adapted* to reach the resources, food, etc., of the environment.
(iii) The survivors in the *struggle for existence* have certain favourable *variations*.
(iv) The favourable variations are *heritable*, now known to be due to changes in the genotype or genetic structure.
(v) The heritable variations will be more pronounced in future generations until a *new species* is formed.
(vi) Nature or the environment *selects* those individuals best fitted for survival, by *natural selection*.

The ancestral giraffes which showed the *variation* of being taller and in having longer necks than the others survived in times of food shortage. They also had an *advantage* in being the first to see predators and flee, and thus to survive and reproduce.

17.5 GENETICS AND EVOLUTION

In Chapter 16 the origin of *variations* in individuals was explained as being due to the effect of gene and chromosome *mutations*, and also due to *recombination* following sexual reproduction. *Heritable* variations are of two kinds, the discontinuous (qualitative inheritance) and the continuous (quantitative inheritance). These are the variations which participate in organic evolution.

In the same way as the *gene* is the *unit* of inheritance, the breeding *population*, instead of the individual, is the *unit* of *evolution*. This aspect of genetics is called *population* genetics.

A *population* is a group of individuals of the same species, of all ages, interbreeding freely in a certain *area*. For example, a rabbit population in a rabbit warren, or bacteria population in a petri dish culture.

The modern evolution theory or *neo-Darwinism* is concerned with combining the theory of natural selection with modern genetics and relating it to *populations* rather than to *individuals*.

17.6 GENE POOL

Every individual in a population has its own *set* of genes. These together with genes from other individuals in the population will form the *gene pool*.

A gene pool can be compared in a simple way to the mixture of black and white beads used in Experiment 16.1; this pool or reservoir provides genes which pair with others in a random manner in fertilisation.

The genes that are most *numerous* in the gene pool will tend to occur most frequently in a particular population. This could be achieved in the bead experiment by removing, say, the black beads and replacing with white beads. In this way the *frequency* of one gene, or white bead, has been increased, and the frequency of the other gene, or black bead, decreased.

When a *population* is reproducing it will draw genes from the gene pool. Those genes present in greatest numbers in the gene pool, white beads, will occur *most* frequently in the next generation of the population.

17.7 FACTORS AFFECTING THE GENE POOL

(a) Mutation

Mutation (Sections 16.3 and 16.4) is a sudden change in the gene or chromosome structure. If the genes or chromosomes had never changed, new species would not have been formed, and evolution would not have occurred.

Mutation is a source of *variation* in a population.

(b) Migration

Migration is caused by individuals of the same species entering or leaving the population by immigration or emigration. In this way *sets* of genes would be removed or added to the gene pool.

(c) Artificial selection

This can be brought about by plant and animal breeders, who remove or add individuals to their breeding populations. This is done by selecting a certain *phenotype* which through its *genotype* affects the gene pool.

Man exercises *selection* in the breeding of plants and animals in modern horticulture and agriculture, and increases the rate of formation of new varieties.

Inbreeding of plants is achieved by self-fertilisation whilst in animal husbandry the carefully selected stock have strong phenotypes and are interbred with closely related animals and may be back-crossed (Section 16.8).

Outbreeding is performed between individuals with less relationship. Cross-fertilisation in plants produces F1 generation with *hybrid vigour* which improves or increases a certain character by producing large fruits or increased resistance to disease. Outbreeding of animals is done to increase the *strength* of animal stocks of the same species.

(d) Natural selection

The fossil record shows that certain species of plants and animals which evolved in the past do not exist today. Natural selection operated through *changes* in the environment, allowing certain individual *phenotypes* which are best *adapted* to live, whilst those in the population *least* adapted or handicapped perished. The survivors of natural selection went on to *reproduce*.

Natural selection can be regarded as a *test* for all members of a *population*, the *conditions* of the test being set by the environment. Natural selection is operating on the *phenotype* which *indirectly* selects certain *genotypes*, which in turn contribute to the gene pool. Those that perish and fail to reproduce have their genes *removed* from the gene pool. It is therefore evident that *populations* will evolve provided they possess *heritable* variations. These variations arise from *mutations*, and *recombination* of genes in meiosis and fertilisation.

17.8 SICKLE CELL ANAEMIA

Sickle cell anaemia is a heritable disease due to a mutation of a recessive gene on an autosome which changes normal red blood cell haemoglobin into sickle cell (SC) haemoglobin. The genotype for normal haemoglobin is shown by HH, and the two recessive genes for SC anaemia are shown as hh. These are both homozygous, whilst Hh will represent the *heterozygous* condition which is called the *sickle cell trait*.

HH = normal haemoglobin
hh = sickle cell *anaemia*
Hh = sickle cell *trait*

If blood samples are placed on a microscope slide, and oxygen *excluded* by adding a drop of liquid paraffin oil, the red blood cells use up their available oxygen. The Hh *and* hh red blood cells develop a *sickle* shape, whilst the normal HH red blood cells do not.

People with Hh, the heterozygous condition, have the *sickle cell trait*, and experience above-average breathlessness during exercise or at high altitudes.

People with hh, the homozygous recessive condition, suffer *sickle cell anaemia* and have severe anaemia. Most die as infants or before puberty from anaemia, leg ulcers and rheumatism.

Intermarriage of *sickle cell trait* Hh people may result in their children being 25% hh SC *anaemia* sufferers who die young and do not reproduce; 50% with SC *trait* Hh who can transmit the disease; and 25% HH normal individuals.

The SC anaemia hh children, since they do not live to reproduce, do not contribute to the gene pool, their gene frequency in the gene pool is *reduced*, and in time should be eliminated.

In some East African populations the sickle cell gene has a *high* frequency with 4% of all children born being of hh or with SC *anaemia*. There is also a *higher* frequency of SC *trait* Hh in the population. The reason for this is that SC trait Hh people have a *selective advantage* in being able to *survive* in greater numbers because of a *resistance* to certain malaria diseases, compared to normal HH who have a *lower* resistance. In this way the Hh sickle cell *trait* people are *naturally selected* and the frequency of the h sickle cell gene *increases* in the gene pool, allowing the Hh people to survive and reproduce.

17.9 NATURAL SELECTION IN ACTION

Polymorphism is a term used to describe distinctly different inheritable *forms* within one freely interbreeding species. Examples are seen in red/green *colour-blind* people and normal colour-visioned people; the *sickle cell* anaemia/trait, and normal haemoglobin. The four human blood groups (Section 16.8) are further examples of polymorphism.

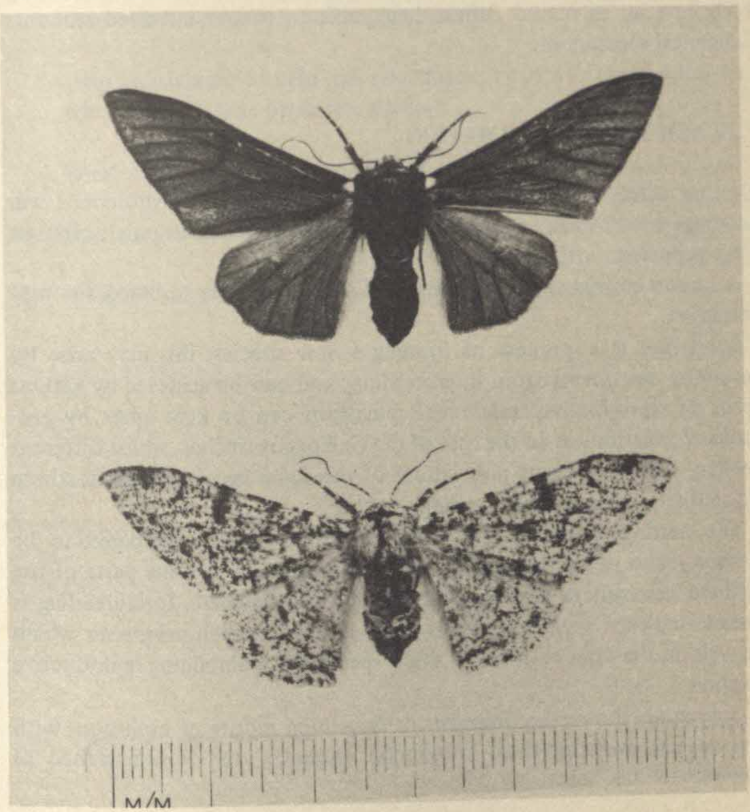
(a) Peppered moth

The peppered moth, *Biston Betularia* (Plate 17.1), is an example of polymorphism in being found as two distinct *forms*, the *black* or melanic form, and *light* or peppered natural form.

In 1848, 99% of the moth population in Manchester was of the *light* form, whilst only 1% was of the black form. Almost 50 years later, 99% of Manchester moth population was of the *black* form, and only 1% was *light*.

The environmental change during the 50-year period was mainly due to air pollution and darkening of the tree trunks with sooty grime. The

plate 17.1 *light and dark forms of the peppered moth,* Biston betularia.
(National Museum of Wales)



light-form moth was easily visible to birds, acting as predators, whilst the *black* form was camouflaged. Natural selection promoted the *black* form of peppered moth whose gene frequency in the gene pool of the particular population *increased*. The gene frequency of the light form decreased since it was unable to survive predation and reproduce.

The genes responsible for the black form gave it a *selective advantage* on soot-covered tree trunks in the polluted air of industrial towns.

In the clean air of the countryside the light form of peppered moth on lichen-covered tree trunks has a selective advantage over the black form. Predator birds, e.g. thrushes, are able to see the black form more easily against the unpolluted tree trunk.

(b) Resistance

Bacteria, insects and rats develop a resistance to antibiotics, insecticides (DDT) and rodenticides ('Warfarin'). Heritable resistant forms develop which have an increased fitness, being able to survive increased amounts of chemical substances.

17.10 NEW SPECIES FORMATION

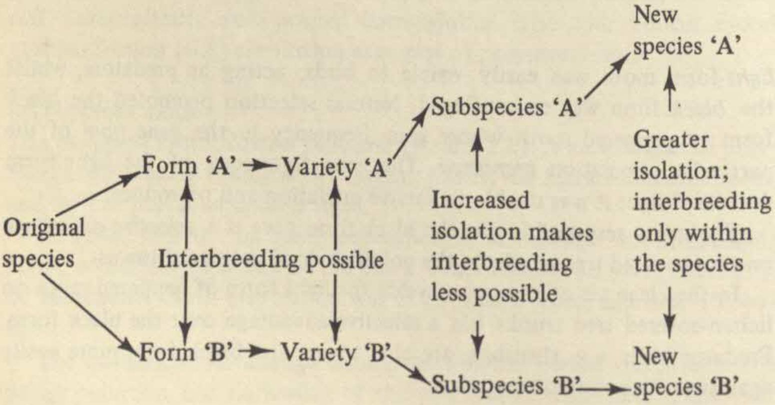
Selection acting on heritable variations in a changing environment will encourage new *forms* of the *same* species. This is seen in polymorphism of the peppered moth.

A *species* consists of a population of organisms able to breed amongst themselves.

Speciation is a process of forming a *new* species; this may arise by *preventing* new *forms* from interbreeding, and can be achieved by various means of *reproductive isolation*. Populations can be kept apart by *geographical* isolation, as in the case of the Galapagos finches, whilst different breeding *seasons* prevent populations of the same species in the northern and southern hemispheres breeding together.

The herring gull and lesser black-backed gull are considered to be extreme *forms* of the same species which interbreed in some parts of the northern hemisphere and are *unable* to do so elsewhere. Interbreeding is possible between *varieties*, and is less possible between *subspecies* which are well on the way to forming a new species by maintaining reproductive isolation.

Speciation shows the *divergent* or *branching* nature of evolution, with new species evolving from a common ancestor, and is summarised as follows.



17.11 QUESTIONS

1 What structural features seen in present-day organisms provide evidence that evolution is still taking place?

2 Give an example of artificial selection and one of natural selection. In what way are these processes similar?

3 What variations are heritable and non-heritable? How do they arise?

4 Explain the term adaptation and how it is related to evolution.

5 Describe ways by which organisms become fossilised.

PART III

ENVIRONMENTAL BIOLOGY

CHAPTER 18

ECOLOGY

18.1 INTRODUCTION

In previous chapters living organisms have been studied as *individuals* with respect to their *nature*, *variety* and *functioning*. Each living organism has the equipment to function and survive as a *separate* entity.

Whether an individual organism survives is dependent on the influence of the *external environment* which will provide it with all its requirements for life: food, warmth, shelter, water, etc.

The *external* environment has two main components: the *biotic* environment due to other living organisms and the *abiotic* environment due to physical conditions of climate or soil and water.

18.2 ECOLOGY

Ecology is the study of the relationship between living organisms and their *environment*. The part of the Earth where living organisms are found is called the *biosphere*, and includes the Earth's surface, soil, oceans, lakes, rivers and the air.

The *habitat* is the place where organisms live, for example a hedge, seashore, a tree, under a stone, leaf litter or a compost heap.

(a) Levels of biological organisation

(i) *Individuals*

The particular *characters* of an individual will identify its *species*.

(ii) *Population*

Individuals of the *same* species of different ages in a certain area at the *same* time form a population.

(iii) *Community*

This is a naturally occurring group of *different* organisms living together in a habitat, with each population interacting with each other. A community can be seen in a rock pool habitat composed of populations of seaweeds, barnacles, periwinkles, wild crabs, limpets, algae, mussels, sea anemones and tubeworms.

(iv) *Ecosystems*

Ecosystems are *areas* composed of a *community* of organisms *interacting* with each other in the *biotic*, living environment, and with the *abiotic*, non-living environment. Examples of ecosystems range from the very small, for example a pool, to the very large, heath or moorland.

Ecosystems are composed of organisms with different *jobs* or ways of life, particularly concerned with feeding. This is called its *niche* or the role of the organism in the ecosystem.

18.3 IDENTIFICATION OF THE SPECIES

Individual organisms in a habitat require *identification* of their *species* as part of any fieldwork or habitat investigation.

Identification of a species is done using a simple *identification key*. Handbooks or natural history guides contain identification keys for wild flowers, trees, insects, fishes, birds and mammals. The books may have *keys* for particular habitats such as seashore, woodlands, fresh water or hedgerows.

More comprehensive means of flowering plant identification can be obtained from various published *flora*.

18.4 INVESTIGATING A NATURAL HABITAT

Plant and animal communities can be studied in a variety of *natural* habitats, a tree, hedgerow, freshwater pond or field.

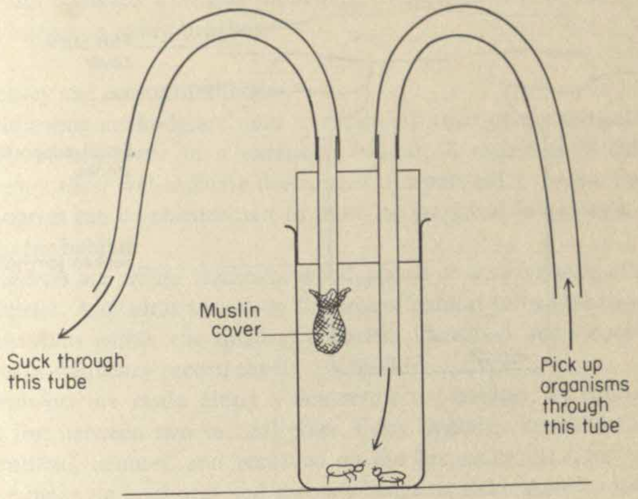
Fieldwork requires equipment for *collecting* samples of organisms for purposes of *identification* of the species in a habitat. These are then recorded in *species lists*.

(a) Collecting methods

(i) *Short vegetation and litter*

For short vegetation and litter, as on a lawn, mown field or woodland, a *pooter* (Fig. 18.1) is used to suck up small delicate living organisms after locating them with a magnifier or hand lens.

fig 18.1 *a pooter collecting tube*



(ii) *Long vegetation*

For long vegetation, as in waist-high pasture, a *sweep net* is used, and the pooter is then used to pick up the organisms from the net.

(iii) *Trees and shrubs*

Place a white sheet on the ground beneath the tree or shrub. Alternatively use an inverted open umbrella in a tree. Beat the branches sharply three or four times with a walking stick, thus dislodging the organisms onto the sheet or into the umbrella. Sweep nets can be used amongst large tree branches.

(iv) *Ground level organisms*

These can be collected with a *pitfall trap*, a jar sunk into the ground with its top rim level with the ground surface (Fig. 18.2). A cover is made with a flat stone or tile supported by smaller stones.

(v) *Soil organisms*

Such organisms present in a turf or leaf mould are collected by placing the soil or mould sample on the supporting grid of a *Tullgren funnel* (Fig. 18.3), which is above a beaker of water, or formaldehyde (methanal) solution; the latter kills the organisms.

fig 18.2 *a pitfall trap for collecting small soil animals*

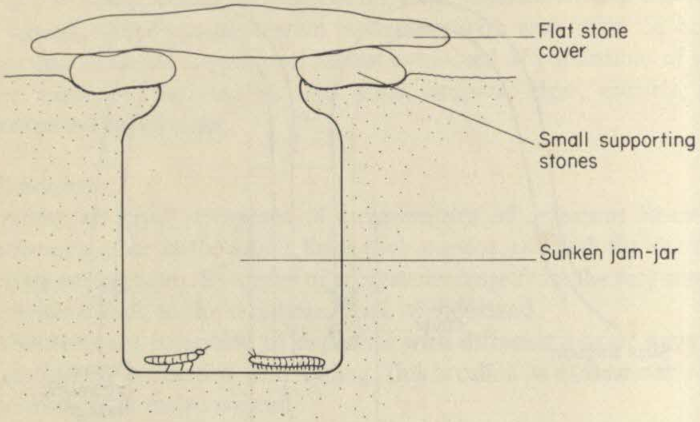
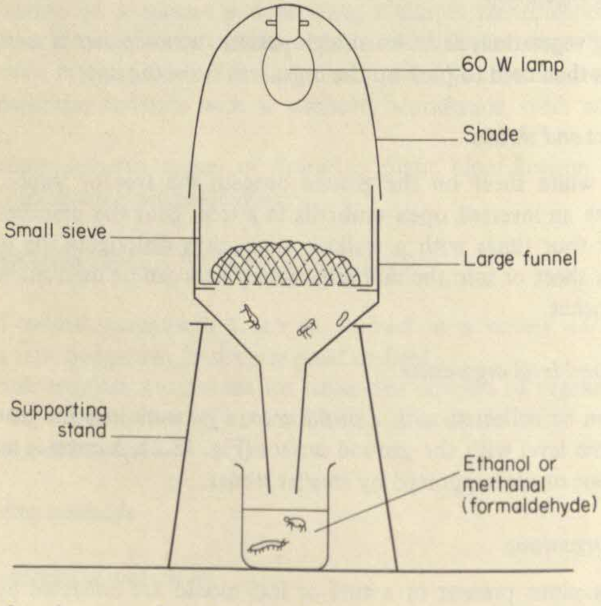


fig 18.3 *the Tullgren funnel for collecting small animals from soil*



A reading lamp is placed at the funnel open end, to heat the sample, for 6 to 8 h. As the sample dries it also drives the organisms downward to fall into the water or preserving solution.

(vi) *Aquatic organisms*

These are collected with fine mesh *nets*, or small *trawl* nets, and by means of fine *sieves* on sandy beaches.

(b) Survey and census methods

The following methods are used to obtain information concerning the *frequency* of organisms in a particular habitat. A record sheet called the *frequency sheet* will indicate the number of a particular species. From this a histogram can be constructed to show the graphical frequency of organisms in the habitat.

Quadrats are *square* frames of wood, plastic or wire between 10 cm and 1 m square. A quadrat is laid on the area of habitat to be investigated and all organisms *within* the quadrat collected, identified and recorded on a species or frequency record sheet.

Transects are made along a *line across* the habitat, by connecting a string line between two vertical poles. Every organism *touching* the string is identified, counted and recorded on the frequency list. Line transects can be made on seashores and across a hedge or field. Another method is to place the quadrat at *stations* 5 or 10 m apart along the line and count the species within the quadrat.

18.5 SOIL

Soil can be part of the *environment* for some organisms and a *habitat* for others. The life of many organisms depends directly or indirectly on soil.

(a) Soil composition

The following are some of the main constituents of a soil.

(i) *Mineral components*

Mineral components (Fig. 18.4) of soil are sand, mineral salts, silt, clay and gravel, all of which are obtained by the *weathering* of rocks through the action of wind and water *erosion*, temperature changes, and particularly freezing of water in rock crevices which splits the rock.

The physical condition of a soil partly depends on its mineral components. Table 18.1 compares sandy and clay soils.

Experiment 18.1 *to estimate the solid mineral components of a soil*

Procedure

(i) *Feel* a fresh sample for grittiness (sand), stickiness (clay) and silkiness (loam).

fig 18.4 *experiment to separate the solid components of soil by physical analysis*

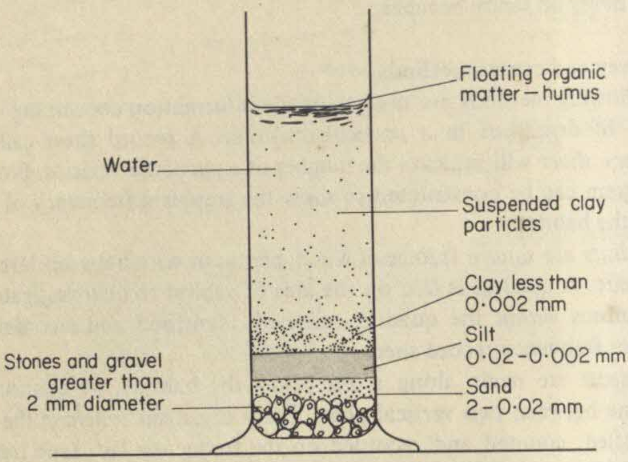


Table 18.1 *comparison of sandy and clay soils*

Feature	*Sandy soil*	*Clay soil*
Particle size	Large – average 1000 μm	Small – average 25 μm
Air space (unless waterlogged)	Large – abundant air	Small – limited air
Water	Poor – salts leached (improved with humus)	Good – salts retained by strong attraction
Drainage	Rapid – soil dries out, and blows away	Slow – soil wet, sticky and cakes dry
Cultivation	Light – easy to dig	Heavy – hard to dig
Improvement	1 Add clay 2 Add humus to aggregate particles 3 Surface mulch prevents evaporation	1 Add sand 2 Add lime to flocculate or aggregate particles to form *crumb* 3 Winter digging for aeration

(ii) Shake a sample (30 g) with about 200 cm^3 water in a 250 cm^3 measuring cylinder, and leave to settle by sedimentation.
(iii) Estimate the width of each layer from the lowest: gravel, sand, silt and clay.

(ii) *Soil water*

Soil water is a dilute solution containing various soluble inorganic mineral salts, forming a *film* around the mineral soil particles. The film of water moves upwards through the soil air spaces by *capillarity* and evaporation into the air.

Some water, called *hygroscopic* water, is in *chemical* combination with soil particles, and is not available for plant use.

Experiment 18.2 *to estimate the total water in a soil*

Procedure

(i) Place a weighed soil sample to dry to a constant weight in an oven at 110°C.
(ii) Reweigh and determine the loss in weight due to evaporation of total soil water.
(iii) Percentage loss can be calculated from:

$$\frac{\text{loss in weight}}{\text{original wet weight}} \times 100 = \text{percentage of water in soil}$$

The total water varies between 10 and 35%.

(iii) *Soil air*

Soil air is found in the spaces between soil particles. It consists of *less* oxygen and *more* carbon dioxide than atmospheric air. Waterlogged, bog and marsh soils have *no* soil air.

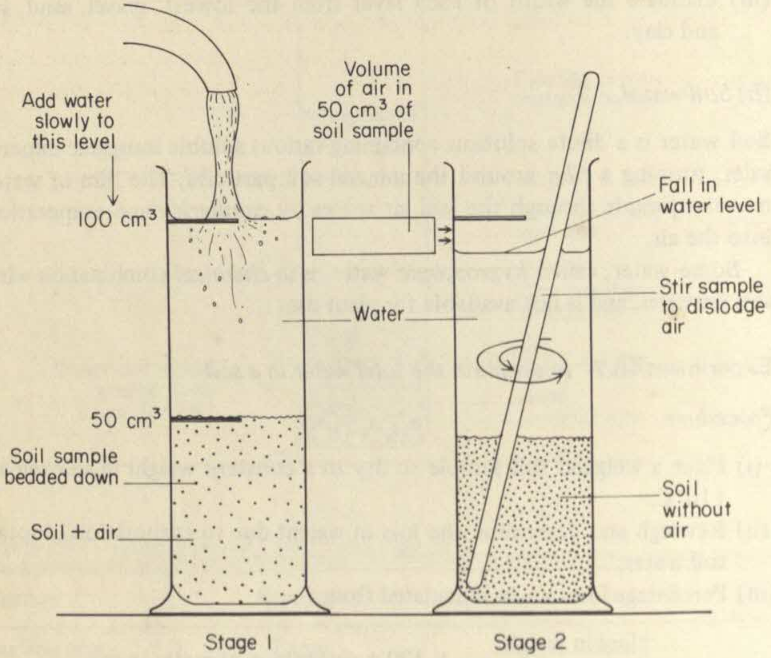
Soil air is needed for aerobic respiration of green plant roots, soil organisms and certain aerobic micro-organisms.

Experiment 18.3 *to estimate the volume of air in a soil*

Fig. 18.5 describes the method for estimating the air content of a soil sample. The volume of water needed to restore the water in the large measuring cylinder to its original level, will be equal to the volume of air in the soil. The percentage of air in the soil sample is calculated as follows:

$$\text{percentage of air} = \frac{\text{volume of air in soil}}{\text{volume of soil sample}} \times 100$$

fig 18.5 *experiment to estimate the volume of air in a soil sample*



(iv) *Soil acidity or alkalinity*

A soil will have a certain pH value. *Alkaline* soils are associated with chalky soils. *Acid* soils are found in poorly drained, peaty and marsh soils.

Certain organisms, e.g. conifers and rhododendrons, prefer acid soils, and snails prefer an alkaline chalky soil.

Experiment 18.4 *to estimate soil pH*

Procedure

(i) Mix a sample of soil with distilled water and allow to settle.
(ii) Add a piece of Universal Indicator paper and note the colour change in comparison to the pH value colour chart. A pH value between pH 7 and 1 is *acid*, whilst values between 7 and 14 are *alkaline*.

(v) *Organic content*

Organic content of a soil is due to *humus*, the end product of *decay* of plant and animal material brought about by soil micro-organisms, fungi and bacteria.

Humus is an important source of nutrients in the form of nitrates and ammonia for protein synthesis in green plant nutrition. It is also a food for soil organisms such as earthworms and insect larvae (Fig. 18.16).

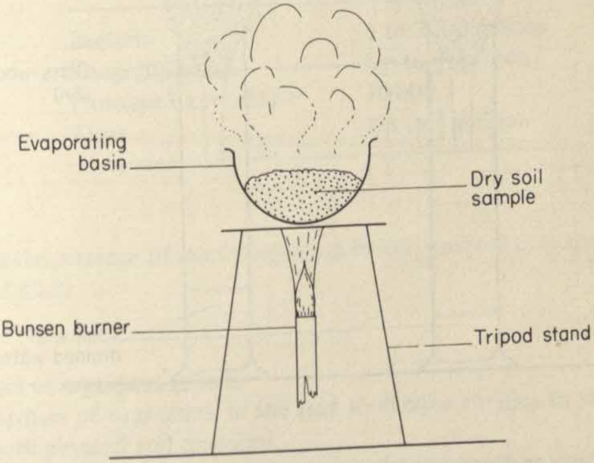
Humus is a *colloidal* organic compound which has water-absorbing properties, and retains water by hygroscopic action; its adhesive properties improve sandy soils and also cause clay soil particles to cling to the humus fibres.

Experiment 18.5 *to estimate the organic content of a soil* (Fig. 18.6)

Procedure

(i) Obtain an oven-dried sample of soil.
(ii) Weigh a sample into an evaporating basin.

fig 18.6 ***experiment to estimate the organic or humus content of a soil sample***



(iii) Heat strongly over a bunsen burner in order to oxidise all carbon-containing humus and other material.
(iv) Allow to cool and determine the loss in weight. Calculate the organic content from:

$$\frac{\text{loss in weight}}{\text{weight of original dry sample}} \times 100 = \text{percentage of organic matter in the soil}$$

(vi) *Soil drainage and permeability*

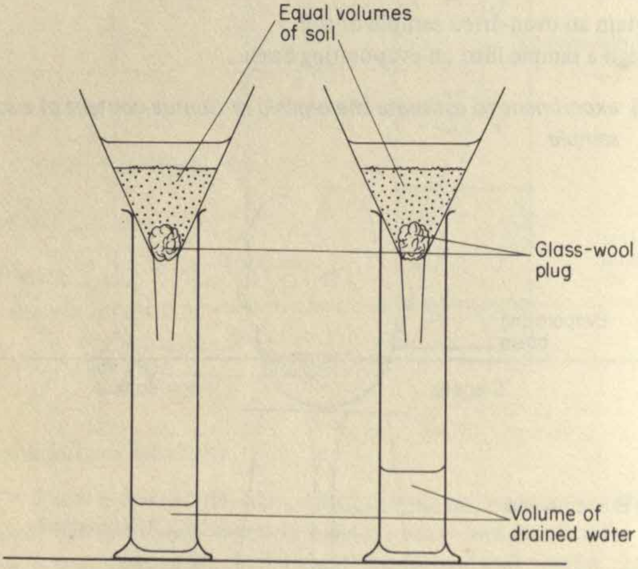
The water-holding capacity and drainage of a sandy, clay or peaty loam soil differs due to the mineral content, air space and organic content.

Experiment 18.6 *to compare soil drainage* (Fig. 18.7)

Procedure

(i) Place equal volumes of samples of different kinds of soils in filter funnels containing a small plug of glass wool. Support the funnels above measuring cylinders.

fig 18.7 *experiment to compare the drainage properties of soils*



(ii) Pour an equal amount of water into each funnel of soil and carefully note the volume of water draining into the measuring cyclinder. The amount which drains in a given time is an indication of the soil drainage and water-holding capacity.

18.6 SOIL AS A HABITAT

Soil is the habitat for large and small organisms, and microscopically small organisms or *micro-organisms.*

The Tullgren funnel (Fig. 18.3) shows how a variety of organisms can be collected from a soil sample. The main organisms are earthworms, centipedes and millipedes, slugs and certain snails, and many insect larvae.

Experiment 18.7 *to count earthworms*

Procedure

(i) Place a 1 m^2 quadrat on the ground and use either plain water or a dilute solution of mustard condiment to water the ground.

(ii) Count the number of earthworms and other organisms which emerge.

(iii) Knowing the number of earthworms in a square metre, calculate the number in a hectare:

number in square metre × 10 000 = number in a hectare

(a) Soil micro-organisms

The following is an estimate of the *number* of micro-organisms in one *gramme* of soil:

Bacteria	1 to 3000 million
Fungi (moulds)	Up to $\frac{1}{2}$ million
Protozoa (*Amoeba*)	10 000
Algae	Up to $\frac{1}{2}$ million

To show the presence of micro-organisms in soil, proceed as in Experiments 19.1 and 19.2.

(b) Effect of organisms in soils

The activities of organisms in soil lead to various changes in soil composition both physical and chemical.

Decomposition: certain organisms, saprophytic bacteria and fungi, feed on dead and decaying soil materials and release certain chemical elements as ions (Section 18.10).

Aeration of soil occurs by various burrowing organisms, earthworms and moles; this also improves drainage.

Cultivation occurs when soil from lower levels is brought to the surface by earthworm 'casts' and by moles and rabbits; this brings soil mineral salts to the surface.

Aggregation or clumping of small soil particles into larger particles, together with neutralisation of soil acidity, occurs in the earthworm gut.

Associations form between soil bacteria and fungi with green plant roots as *nodules* and *mycorhiza* (Section 18.7).

18.7 INTERRELATIONS BETWEEN ORGANISMS

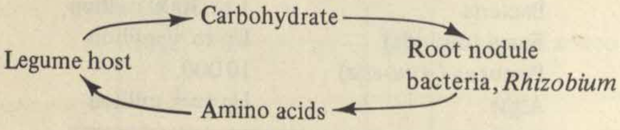
Living organisms have a wide range of *association* between individuals or populations of similar or different species. It may range from *competition* for food, light or mates, to the extreme of *predation* where one kills and eats another.

(a) Symbiosis

The is an association between different organisms which brings *benefit* to both the *host* and *symbiont*.

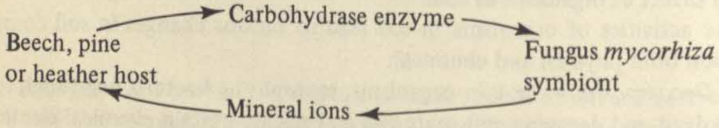
(i) *Root nodules*

The legume plants, pea and bean, are the *hosts* to *symbiont* bacteria, which inhabit the host roots forming root nodules. The root nodule bacteria *fix* nitrogen gas in soil air, converting it into amino acid which the host uses. In return, the host provides the bacteria with carbohydrates.



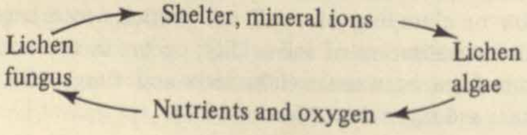
(ii) *Mycorhiza*

Mycorhiza are associations between the roots of plants growing in *acid* soils and certain *fungi*. The *host* is a pine, beech or heather and it provides the fungus with an *enzyme* to digest carbohydrates in leaf litter. In return, the fungus *symbiont* passes mineral ions from the soil to the host.



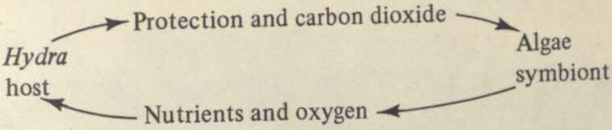
(iii) *Lichens*

Lichens are *dual* organisms composed of a symbiotic association of *algae* living within a *fungus* mycelium. The lichens grow on exposed rock surfaces and are important colonisers of bare ground.



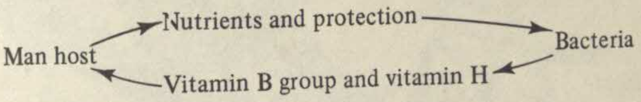
(iv) *Hydra*

Hydra endodermis cells contain unicellular algae, *Chlorella* sp.



(v) *Intestinal bacteria*

These are present in the large intestine of man. These symbiotic bacteria produce vitamins of the B group, B_1, B_2, B_6, B_{12}, nicotinic acid and vitamin H, in return for protection and food nutrients.



Antibiotics can destroy these symbiotic bacteria. In herbivores the symbiotic bacteria produce an enzyme, *cellulase*, to digest cellulose.

(b) Parasitism

This is an association between a *host* and a *parasite* which involves providing the parasite with food, protection and conditions for its survival. The parasite may or may not harm the host.

(i) *Ectoparasites*

Ectoparasites live *outside* the host's body.

Plant/plant parasites are seen in the dodder (Fig. 18.8), a plant parasite on nettles, heather and gorse. The parasite sends *haustoria* directly into the host vascular bundles. Some fungi are parasites, causing *blight* in potatoes and *rusts* in wheat (Section 19.5).

Plant/animal parasites are seen as the fungus, *Trichophyton* sp., growing on human skin, hair and nails, causing *ringworm* and athlete's foot (Plate 18.1).

Animal/animal parasites include fleas (Plate 18.2), lice, ticks and mosquitos. Some cause infected bites, others *transmit* plague, typhus, tick fever and malaria (Section 19.6).

Animal/plant parasites include greenfly or aphids, and eelworms in potatoes.

plate 18.1 *a plant and animal parasite relationship of the scalp ringworm,* Trichophyton *sp., fungus on human hair (Bayer Chemical Co. Ltd)*

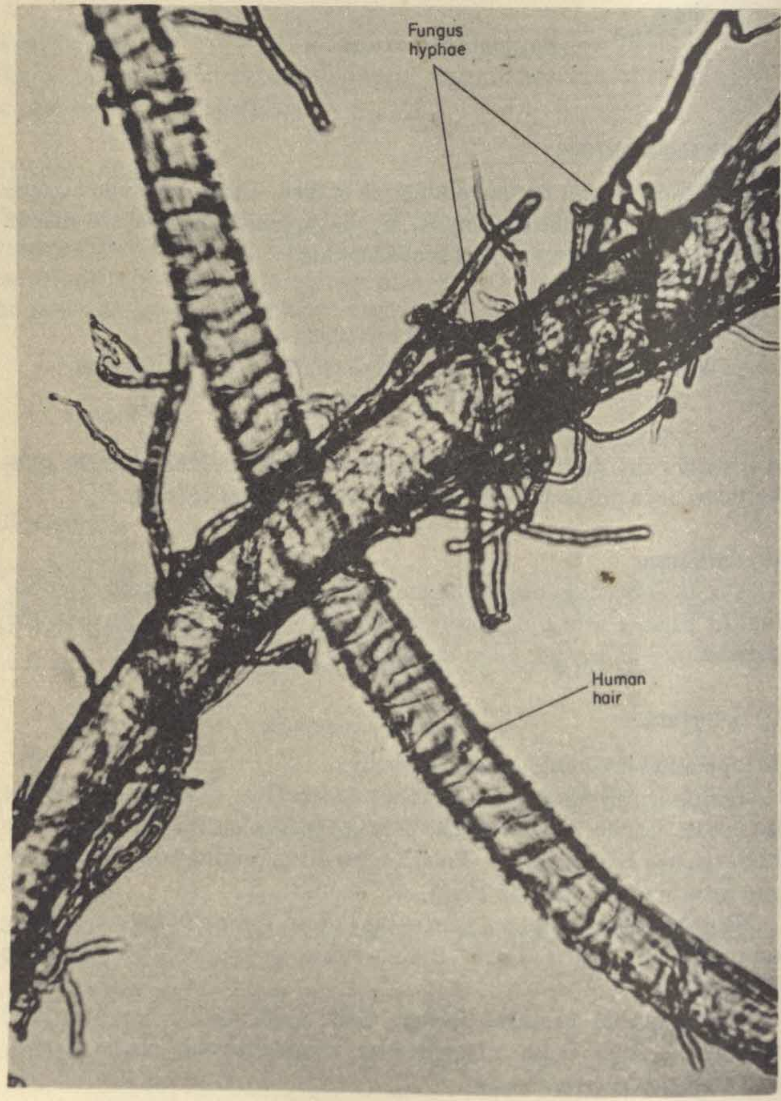


plate 18.2 *a photomicrograph of the human flea,* Pulex irritans, *an ectoparasite (Rentokil Laboratories Ltd)*

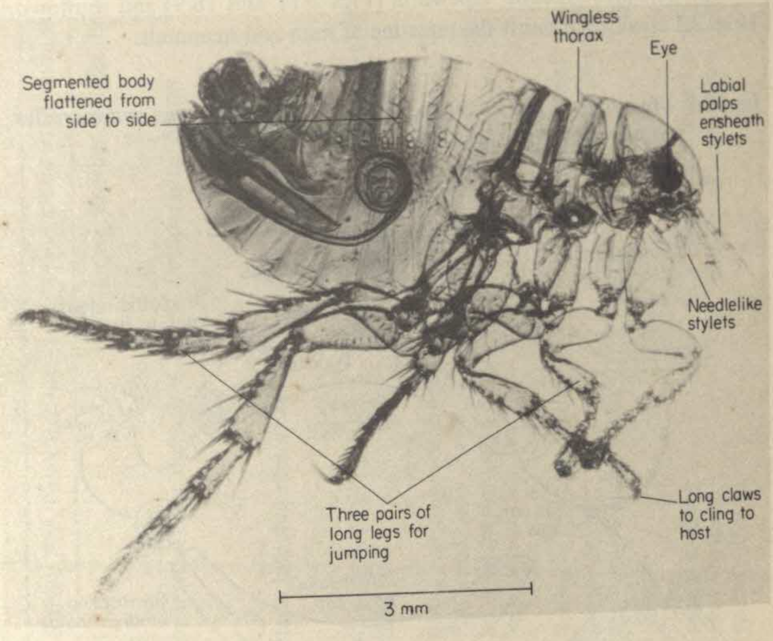
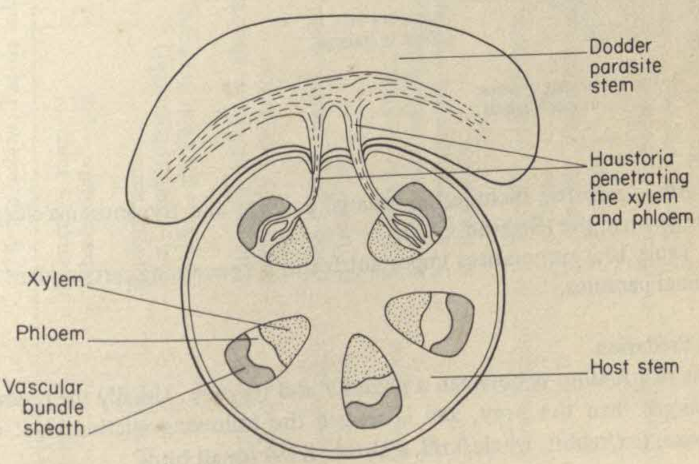

Wingless thorax
Eye
Segmented body flattened from side to side
Labial palps ensheath stylets
Needlelike stylets
Long claws to cling to host
Three pairs of long legs for jumping
3 mm

fig 18.8 *the dodder plant,* Cuscuta *sp., a twining rootless ectoparasite on nettles,* Urtica *sp., gorse,* Ulex *sp., and heather,* Calluna *sp.*

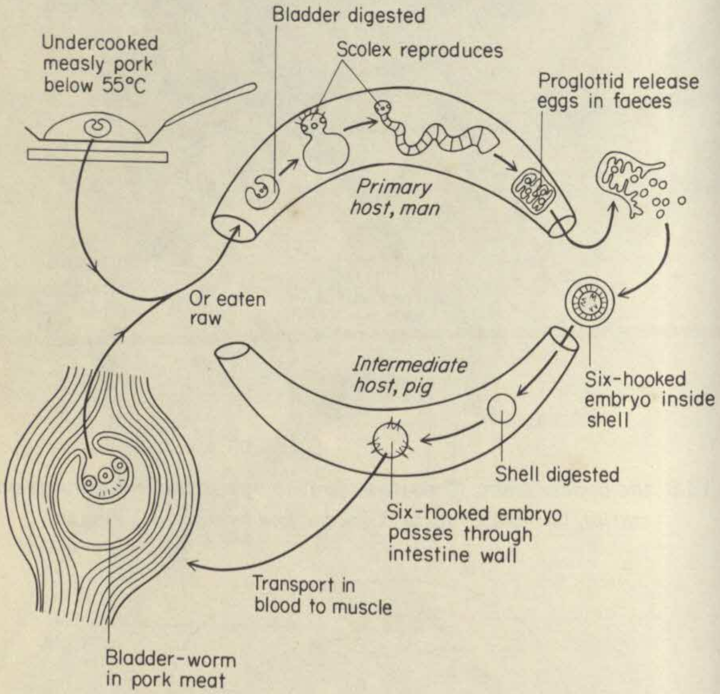


(ii) *Endoparasites*

Endoparasites live *inside* the host.

Gut parasites include tapeworm (Figs 2.11 and 18.9) and roundworm (Fig. 2.12) which inhabit the intestine of man and mammals.

fig 18.9 *life-cycle of the pork tapeworm,* Taenia solium, *an endoparasite of man and the pig*


Bladder digested
Undercooked measly pork below 55°C
Scolex reproduces
Proglottid release eggs in faeces
Primary host, man
Or eaten raw
Intermediate host, pig
Six-hooked embryo inside shell
Shell digested
Six-hooked embryo passes through intestine wall
Transport in blood to muscle
Bladder-worm in pork meat

Blood parasites include the malarial parasite and trypanosome sleeping sickness parasite (Section 19.6).

Table 18.2 summarises important features concerning certain plant and animal parasites.

(c) Predation

This relationship is between a *predator* and its *prey*. Usually the predator is *larger* than the prey, and is seen in the following relationships: cat/mouse, fox/rabbit, whale/krill, seal/fish, hawk/small birds.

Table 18.2 *summary of plant and animal parasites*

	Pig tapeworm, Taenia solium	*Human flea*, Pulex irritans	*Dodder*, Cuscuta sp.
Host	Primary – man Intermediate – pig	Man	Gorse, heather, nettles, broom
Location	Endoparasite: Gut – man (proglottid) Muscle – pig (bladderworm)	Ectoparasite: Skin and hair	Ectoparasite: Stems
Harm caused to host	Man – gut blockage, abdominal pain, body weight loss	Bacteria infected skin bites	Stunted growth
Benefit gained by parasite	Food supply, shelter, steady environment	Food supply from blood, shelter	Food from phloem, water, salts from xylem, support
Adaptations	1 Hooks and suckers 2 Protective anti-enzyme cuticle 3 Large absorptive surface area 4 Anaerobe	1 Biting, sucking mouthparts 2 Flattened body shape 3 Leaping method of locomotion	1 Penetrating haustoria 2 Twining stem
Reproduction	1 Sexual – many thousands of eggs 2 Asexual – budding proglottids 3 Two hosts	1 Sexual – few eggs laid in house crevices 2 Larva/pupa survive 6 to 12 months	1 Numerous flowers 2 Large numbers of seeds
Control	1 Meat inspection 2 Sewage disposal 3 Thorough pork cooking 4 Male fern extract to expel tapeworm	1 House hygiene 2 Body hygiene 3 Insecticides	1 Burning infected plants 2 Not of economic importance

18.8 PROCESSES IN THE ECOSYSTEM

The main processes occurring in an ecosystem include *feeding* and the *circulation* of chemical elements, together with the *flow* of energy through the ecosystem.

An ecosystem is made up of three main component 'professions': the *producers*, the *consumers* and the *decomposers*. All are concerned with the *feeding* processes, the *circulation* of chemical elements and the *flow* of energy.

Producers are the green *photosynthetic* plants which capture and bring *energy* into the ecosystem. They are able to manufacture organic food from simpler inorganic substances. They are *autotrophic* organisms (see Section 6.1).

Consumers are all animals which obtain energy directly or indirectly from the producers as ready-made *organic* food. They are mainly *heterotrophic* organisms (see Section 7.1). *Primary* consumers are those feeding *directly* on the producers, whilst *secondary* consumers feed on the primary consumers. *Herbivores* eat plants and *carnivores* eat other animals.

Decomposers are the non-green fungi and bacteria which obtain their energy from *solutions* of organic compounds present in dead and decaying plant and animal material and wastes, and which *release* chemical elements as ions. The main chemical ions released by decomposers include nitrates, ammonia, phosphates, potassium and calcium.

(a) Food chains

A food chain shows the *feeding* relationship between organisms in a natural community through which energy is transferred from producers, consumers, to decomposers. All food chains begin with a green plant, and may consist of three to five links or *trophic levels* (Fig. 18.10). The T1 first trophic producer level includes all green plants, grass, phytoplankton, herbs and trees. T2 second trophic level, *primary* consumers, are various small and large *herbivorous* animals, and zooplankton. T3 and T4 are *carnivorous* animals.

Table 18.3 provides examples of food chains in ecosystems.

(b) Food webs

All the different food *chains* in a natural community make up the *food webs* (Fig. 18.11). Simple food chains are rarely found in a community fig 18.10 *examples of trophic levels (T1-T5) in a food chain*

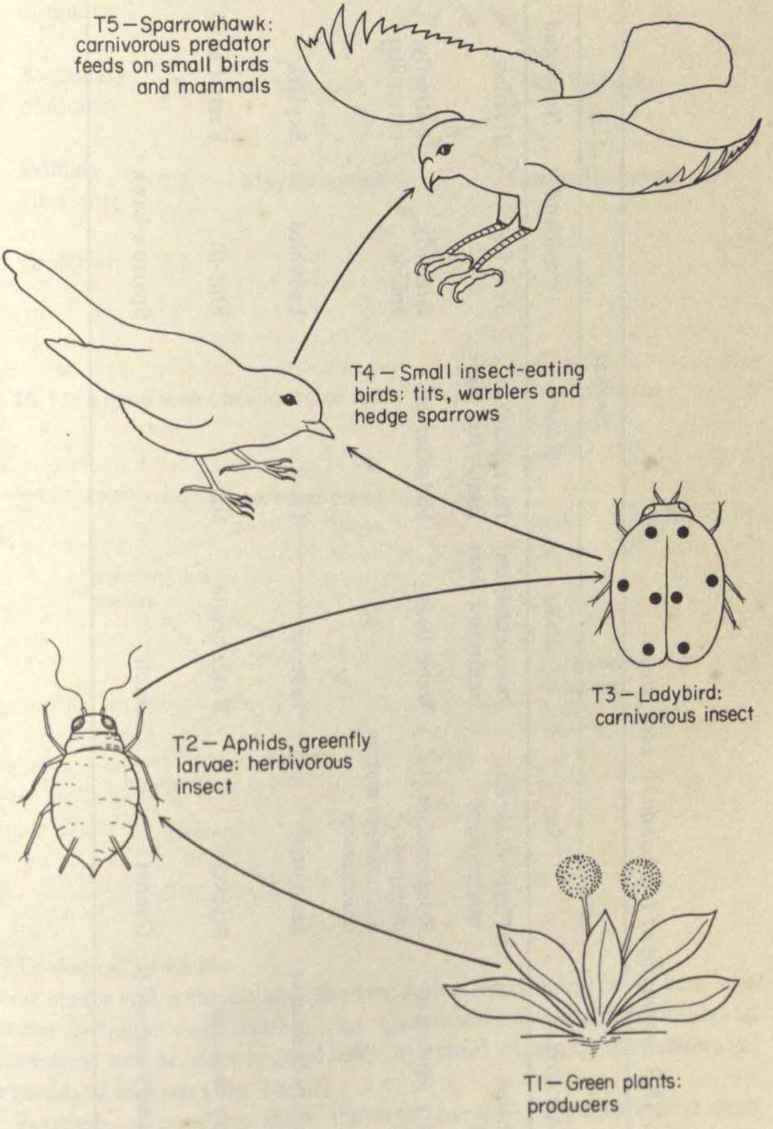

T5 – Sparrowhawk: carnivorous predator feeds on small birds and mammals
T4 – Small insect-eating birds: tits, warblers and hedge sparrows
T3 – Ladybird: carnivorous insect
T2 – Aphids, greenfly larvae: herbivorous insect
T1 – Green plants: producers

Table 18.3 *examples of food chains in ecosystems*

Trophic level	*Habitat*					
	Sea	*Pond*	*River*	*Woodland*	*Heathland*	*Grassland*
Producers T1	Phytoplankton, marine algae	Phytoplankton, freshwater algae	Phytoplankton, freshwater algae	Tree leaf	Heather	Grass
Primary consumer T2	Zooplankton, copepods, microscopic marine crustaceans	Water fleas	Midge larvae	Greenfly, aphids	Butterfly, caterpillar	Grasshopper
Secondary consumer T3	Sand eels	Tadpole	Trout	Ladybird	Skylark	Lizard
Tertiary consumer T4	Mackerel	Water beetle	Man	Blue-tit	Kestrel hawk	Snake
Quaternary consumer T5	Gannet	Perch		Sparrow-hawk		

since most organisms may feed on different organisms in the same trophic or at different trophic levels.

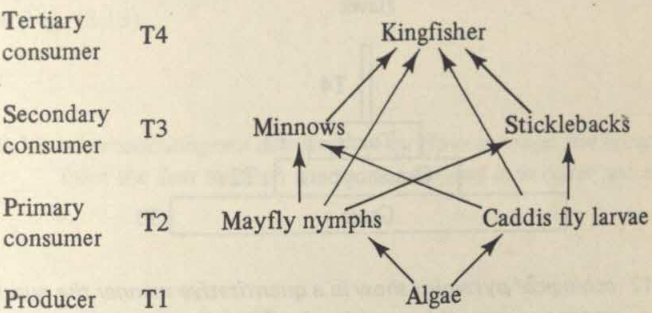
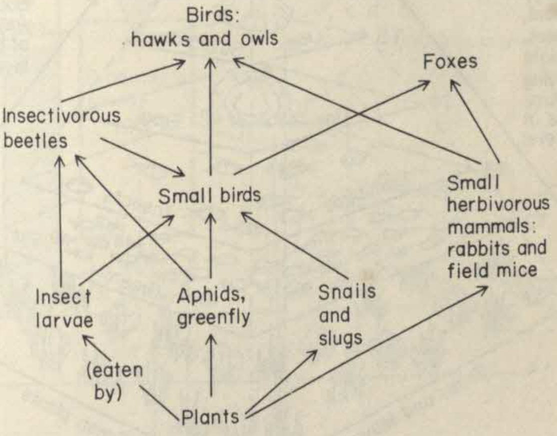


fig 18.11 *a food web composed of many interrelated food chains*



(c) Ecological pyramids

Food chains and webs do not give any indication of *numbers* or *mass* of a species feeding at each trophic level. *Quantitative* feeding relationships in ecosystems can be shown graphically by either pyramids of numbers, or pyramids of biomass (Fig. 18.12).

Pyramids of numbers show the total *number* of individuals at each trophic level. The greatest number of organisms will be found at the T1 producer level. An enormous number of leaves will be needed to feed grasshoppers, which in turn will feed a few toads, which will form a small part of a hawk's diet.

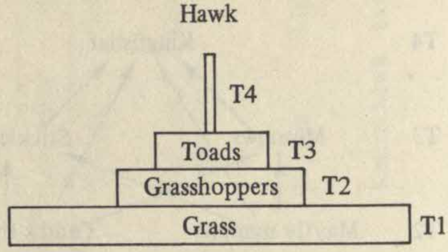
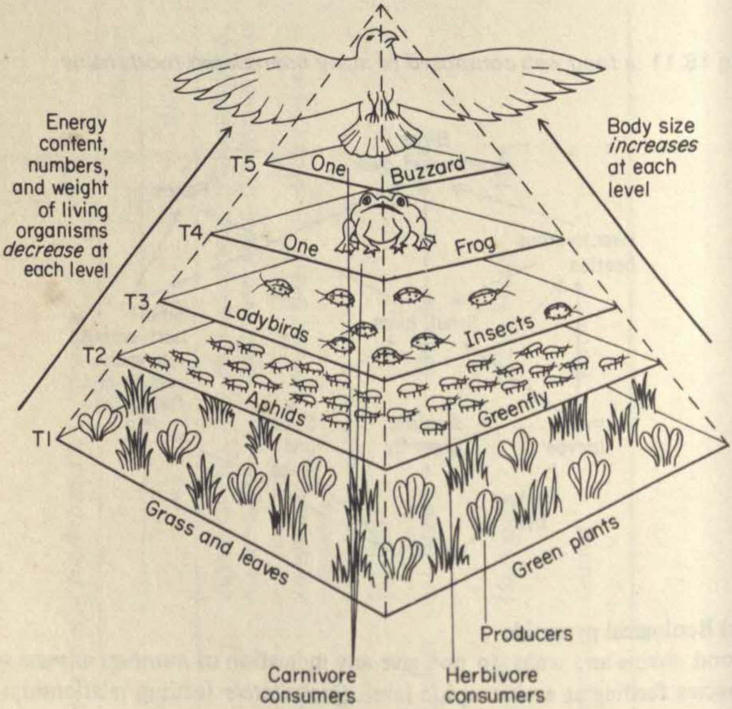


fig 18.12 *ecological pyramids show in a quantitative manner the numbers, energy or mass (biomass) involved in a food chain*



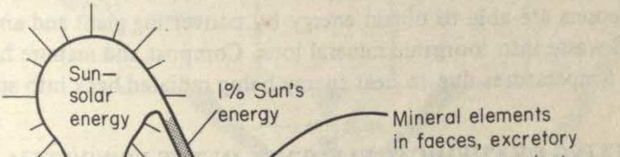
Instead of numbers, the *biomass* or *weight* of all organisms at a trophic level is used to construct a pyramid of biomass.

An *inverted* pyramid of numbers will indicate the number of *ectoparasites* on an animal, for example fleas on a fox.

18.9 ENERGY FLOW IN THE ECOSYSTEM

Energy radiated from the *Sun* 'flows' through an ecosystem passing *through* the different trophic levels, and to radiate again back into outer space (Fig. 18.13).

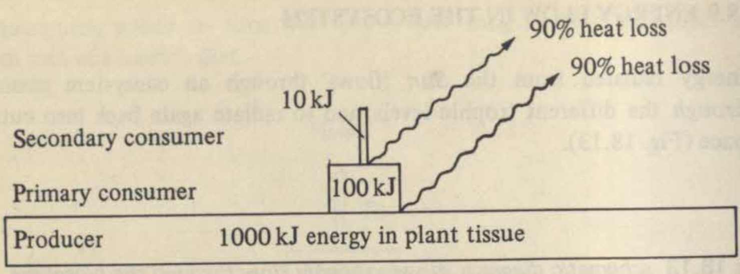
fig 18.13 *schematic diagram showing energy flow through the biosphere from the Sun through the food chain and into outer space*



About 1% of the total energy from the Sun enters the *producers* in an ecosystem. The remaining 99% of solar energy is used to *evaporate* water, *heat up* soil, and is then lost to outer space.

As energy is *transferred* from one trophic level to the next, from producer to primary consumer, between 80 and 90% of the original energy is *lost* as *heat* as a byproduct of respiration.

A *pyramid of energy* can be constructed showing energy transfer in a community of organisms.

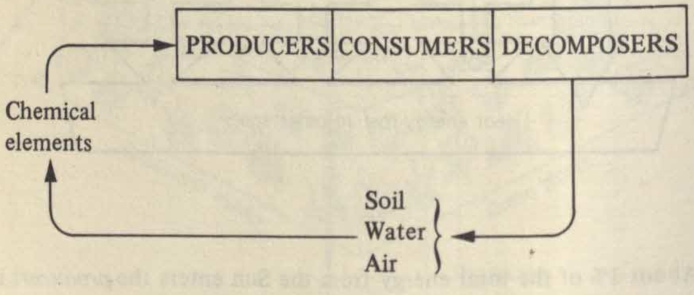


A short food chain of two or three links is better able to support a community more *efficiently* than a long chain of five links where much of the original energy from the producers would never reach those organisms at higher trophic levels.

Decomposers are able to obtain energy by converting plant and animal tissues and waste into inorganic mineral ions. Compost and manure heaps have high temperatures due to heat energy being radiated back into space.

18.10 CYCLING OF CHEMICAL ELEMENTS IN THE ECOSYSTEM

The activities of producers, consumers and decomposers result in the *circulation* of chemical elements in the biosphere. The amount of chemical elements in the biosphere remains *constant* (apart from the amounts fired out into space in space rockets and vehicles). There is *no* inflow of new chemical elements, as in the case of radiant energy. Chemical elements in the biosphere cannot be created or destroyed, they can only be *recirculated* in different chemical forms and combinations.

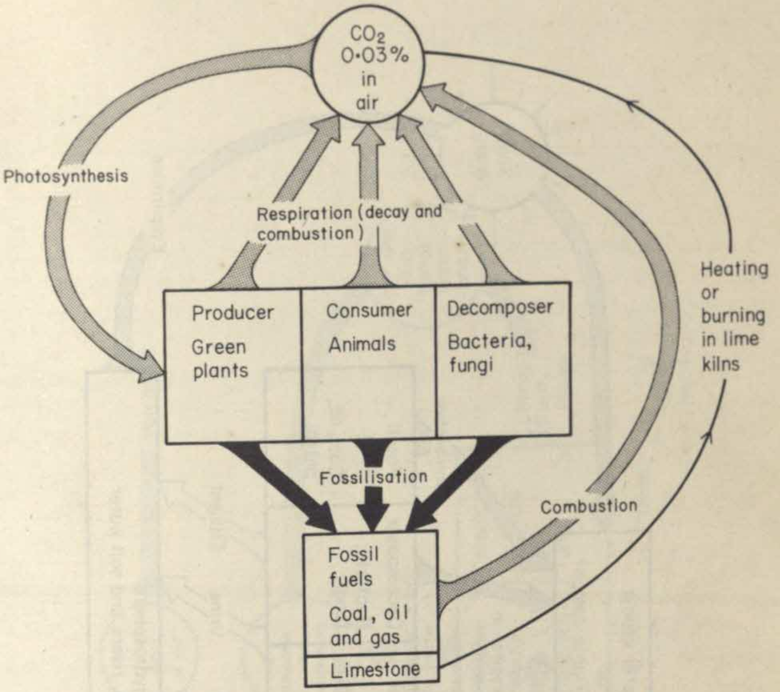


(a) Carbon cycle

Combustion and *respiration*, together with the *thermal decomposition* of limestone, calcium carbonate, all *produce* carbon dioxide which enters the air or dissolves as hydrogen carbonates in water (Fig. 18.14).

Producers synthesise organic compounds from carbon dioxide (Section 6.2).

fig 18.14 *the carbon cycle*



(b) Water cycle

Water is a chemical *compound* of hydrogen and oxygen elements. Therefore, these elements are circulated in a compound form (Fig. 18.15).

The *hydrosphere* is the main *source* of water, which it supplies to the producers, consumers and decomposers in the ecosystems. Green plants are able to *split* up the water into oxygen during photosynthesis (Section 6.5).

Return of water to the hydrosphere is by evaporation by solar *energy*, followed by condensation.

(c) Nitrogen cycle

The *atmosphere* is the source of *gaseous* nitrogen. This is converted to ammonia and nitrates by chemical synthesis and lightning and by blue-green algae, soil and root nodule bacteria into proteins (see Section 18.7). (Fig. 18.16).

Producers use soil nitrates to *synthesise protein* for the consumers (see Section 6.5).

Nitrifying bacteria convert plant and animal nitrogen compounds into fig 18.15 *the water cycle*

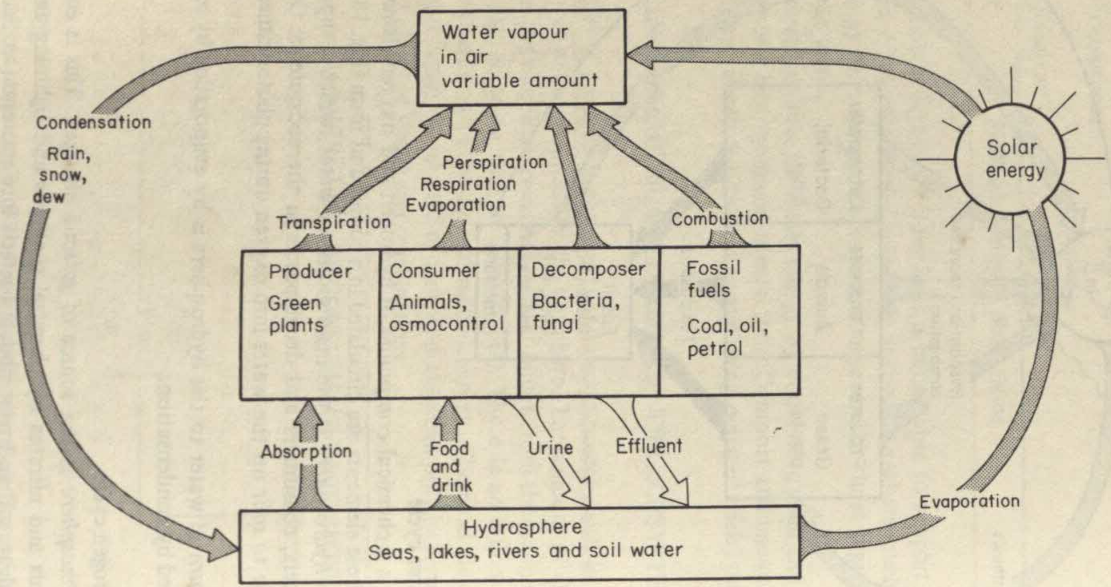
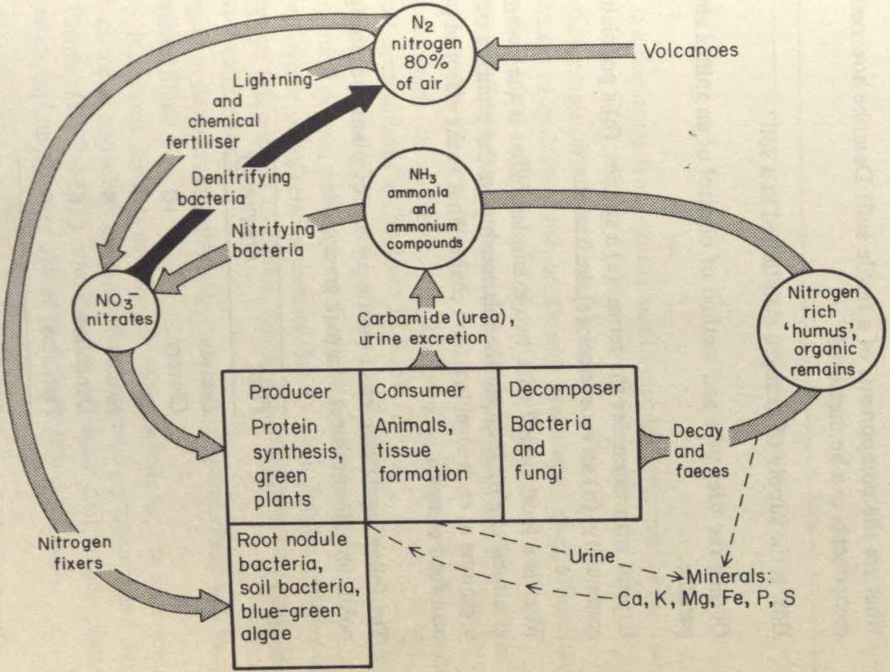


fig 18.16 *the nitrogen cycle*



nitrates returned to the soil. Other *denitrifying* bacteria reduce nitrates to nitrogen which escapes into the atmosphere.

Some nitrates leach into the hydrosphere.

18.11 QUESTIONS

1 Describe the process of decay of a cabbage leaf.

2 What are the components of a fertile soil? Describe how *two* of these components can be measured.

3 How is the supply of nitrogen maintained in a soil?

4 Outline the life-cycle and method of control of an animal and a plant parasite.

5 Explain with examples the terms: (a) a species; (b) a population; (c) a community; (d) an ecosystem; (e) the biosphere.

6 What is a food chain? Give two examples. What is the energy source in a food chain? Indicate the relationship in the numbers or mass of organisms at each level in a food chain. What is the effect of pesticides on a food chain?

7 The following data refer to the frequency of plants occurring at 100 points on a line transect of a park grassy area:

Plant	*Frequency*
Grasses	60
Clovers	10
Daisy	10
Mosses	8
Dandelion	6
Plantains	6

Construct a histogram. Describe the equipment, method and recording used in making a line transect. Describe how a *qualitative* study of a microhabitat can be done using a *quadrat*. How are the organisms identified?

MAN AND DISEASE

19.1 DISEASE

Disease is a departure from normal health through structural or functional disorders of the body.

The main *causes* of disease in man are:

(i) *genetic* or heritable disease, Down's syndrome, spina bifida, haemophilia, etc. (see Section 16.12);
(ii) *nutrition deficiency*, scurvy, beri-beri, pellagra, anaemia, goitre, kwashiorkor (see Chapter 8);
(iii) *homeostasis* or metabolic and hormonal disorders, sugar diabetes, goitre, cretinism (see Sections 12.3 and 13.13);
(iv) *physical* disorders due to accident, injury, heat, cold and radiation;
(v) *chemical causes*, poisoning, drug abuse, smoking, alcohol;
(vi) *pathogenic* or *infectious* diseases due to other living organisms which can be transmitted to others, diphtheria, smallpox, ringworm, tapeworm and malaria;
(vii) *aging* or degenerative diseases – osteoarthritis and artery wall hardening;
(viii) *mental* illness.

Many infectious diseases are due to *micro-organisms*, the microscopically small virus *particles*, the *unicellular* bacteria, protozoa and fungi. Louis Pasteur (1822–1895) was the first to show that certain diseases, fermentation and decay were caused by living micro-organisms.

19.2 WARNING: WORKING WITH MICROBES

The study of micro-organisms is called *microbiology*. Cultures of microbes, bacteria and fungi can be *dangerous*, and can be a source of *infectious disease*.

The following precautions should be strictly observed when performing experimental work.

(i) HANDS. Wash and scrub in hot soapy water before and after experiments. Sterilise the skin by swabbing with cotton-wool soaked in 70% ethanol solution, leave to evaporate.

(ii) BENCHES. Benches and table tops should be swabbed with 5-10% Lysol solution before and after working.

(iii) CULTURE HANDLING. Do *not* remove culture dish lids from incubated cultures, keep them taped down. Do not *breathe* over *sterile* containers or cultures.

(iv) EQUIPMENT. Sterilise glass and metal items in a pressure cooker kept for the purpose and *not* used for cooking at any time. Plug test tubes with *non-absorbent* cotton-wool and leave tops of screw cap bottles *slack*. Sterilise at 6-7 kg pressure for 20 min. Alternatively bake glass and metal items in an oven at 150°C for 30 min. Wire loops and glass bottle mouth openings are *flamed* by passing through a bunsen or spirit burner flame.

(v) DRAUGHTS. Keep doors and windows closed to avoid air currents.

(vi) FINGERS. Never eat, drink, smoke or touch the nose and lips with *fingers* when working with microbes.

(vii) DISPOSAL. Dispose of culture and contaminated apparatus by soaking in 10% Lysol solution for 1-2 days. Rinse and sterilise. Alternatively wrap combustible material in paper and burn in a furnace.

19.3 BACTERIA

Bacteria are found almost everywhere in the soil, air, and on healthy human skin. The total estimated weight of bacteria on Earth is *twenty* times that of all other life on Earth.

(a) Structure

Antony van Leeuwenhoek (1632-1723) was the first to observe bacteria and protozoa with a microscope. A bacterium (*pl.* bacteria) body consists of one cell, with a cell *wall* composed of lipoprotein, and an outer *slime layer* (Fig. 19.1). The cytoplasm contains ribosome organelles, and certain bacteria have chlorophyll.

The nucleus consists of strands of DNA nucleic acid without histone protein, or a nuclear membrane.

Bacteria cells are between 100 and 2000 μm in size and can be seen with a high power light microscope (Plate 19.1) as spheres in bacteria called *cocci*, rods in *bacilli*, spirals in *spirilli*, and comma shapes in *vibrios* (Fig. 19.2). Some bacteria may have one or more flagella.

(b) Nutrition

Parasites on plants and animals cause disease; these are *pathogenic* bacteria.

Saprophytic decomposers are important in decay and cycling of chemical elements.

fig 19.1 *schematic diagram showing the internal structure of a bacterial cell*

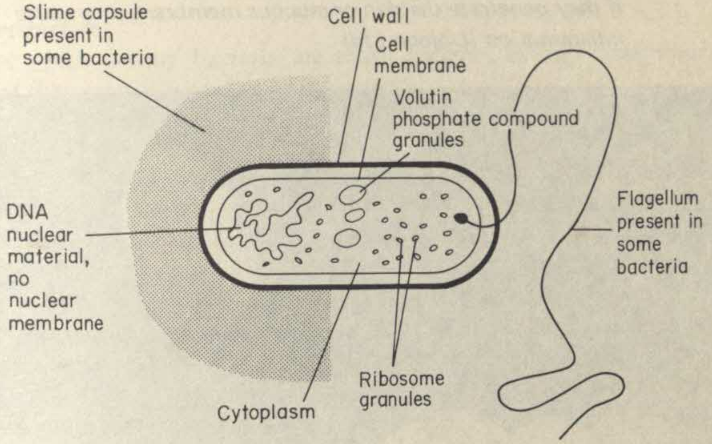

Slime capsule present in some bacteria
Cell wall
Cell membrane
Volutin phosphate compound granules
DNA nuclear material, no nuclear membrane
Flagellum present in some bacteria
Ribosome granules
Cytoplasm

fig 19.2 *different shapes of bacterial cells*

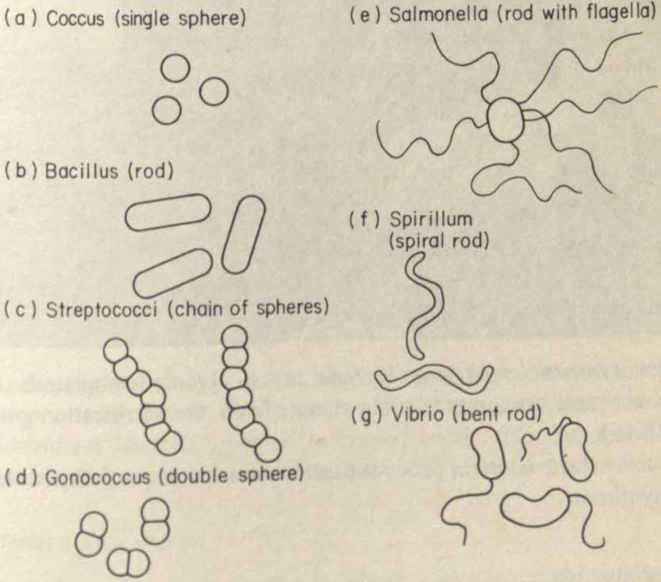
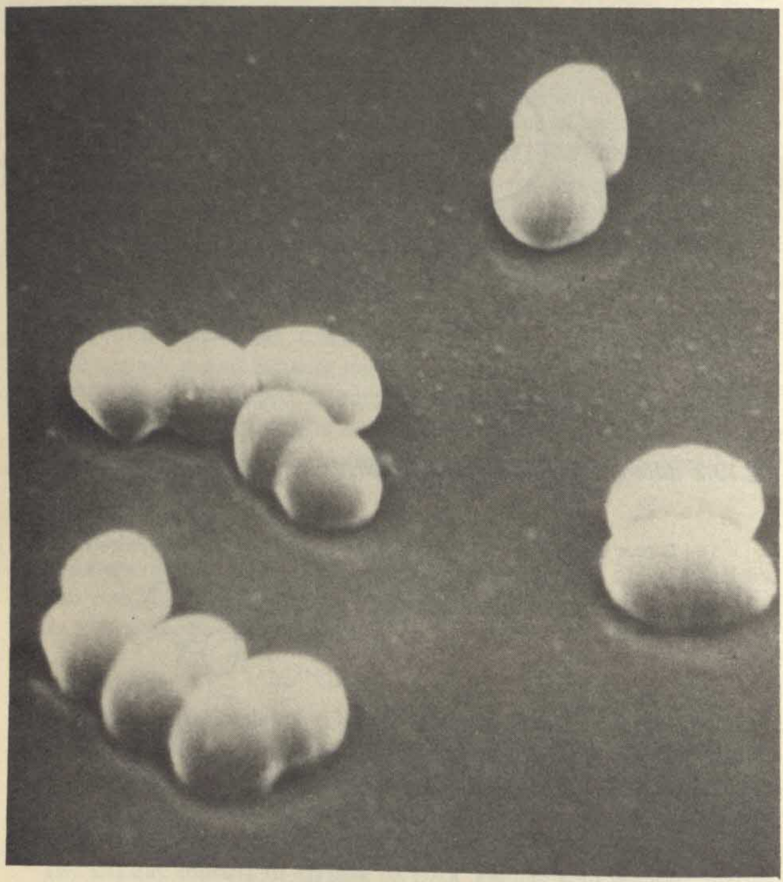

(a) Coccus (single sphere)
(b) Bacillus (rod)
(c) Streptococci (chain of spheres)
(d) Gonococcus (double sphere)
(e) Salmonella (rod with flagella)
(f) Spirillum (spiral rod)
(g) Vibrio (bent rod)

plate 19.1 *an electron micrograph showing the bacteria* Streptococcus viridans *magnified 13 975 times. This bacteria is a normal harmless saprophyte inhabitant of the mouth and throat. If they penetrate the skin or mucous membrane they cause inflammation (Upjohn Ltd)*



Chemosynthetic nitrifying bacteria make organic compounds from simple chemical compounds using energy from the nitrification process (Fig. 18.16).

Photosynthetic bacteria produce organic compounds, carbohydrates, by photosynthesis.

(c) Reproduction

Bacteria are cultured on moist nutrient media containing organic food materials at a temperature of 38-40°C, in the absence of light. Reproduction is by asexual binary fission to form groups of cells or *colonies* visible to the naked eye (Section 15.2).

(d) Destruction

Agents which destroy bacteria are called *bactericides* and those which prevent their growth are called *bacteriostats*.

(i) *Heat*, dry in baking oven 150°C, or wet steam in pressure cooker at 110°C.

(ii) *Chemicals*, phenols (lysol and carbolic), sodium hypochlorite (household bleach), ethanol 70%, methanal (formaldehyde), sulphur dioxide gas, hydrogen peroxide and soap. Joseph Lister (1827-1912), a surgeon, was the first to use chemical antiseptics in surgery.

(iii) *Radiation*, ultra-violet light and X-rays and gamma-rays.

(iv) *Antibiotics*, sulpha drugs and vaccines.

Certain bacteria can survive as *spores* resistant to moist heat, chemicals and low temperatures (Fig. 15.3).

(e) Beneficial bacteria

Nitrogen-fixing and nitrifying bacteria in soil increase the soil nitrogen content.

Gut bacteria produce vitamins of the B group and the enzyme, cellulase content (Fig. 18.16).

Antibiotic synthesis of *streptomycin, tetracycline* and *neomycins* is by certain soil bacteria, bacilli and *Streptomyces* species (Plate 19.2).

Food fermentation occurs in cheese, butter, yoghourt and agricultural silage.

Sewage breakdown is due to bacteria acting as decomposers.

Industrial processes, tobacco curing, vinegar manufacture, butter, cheese, linen and leather making involve bacterial action stages.

(f) Harmful bacteria

Soil denitrifying bacteria reduce the nitrogen content of soil (Section 18.10).

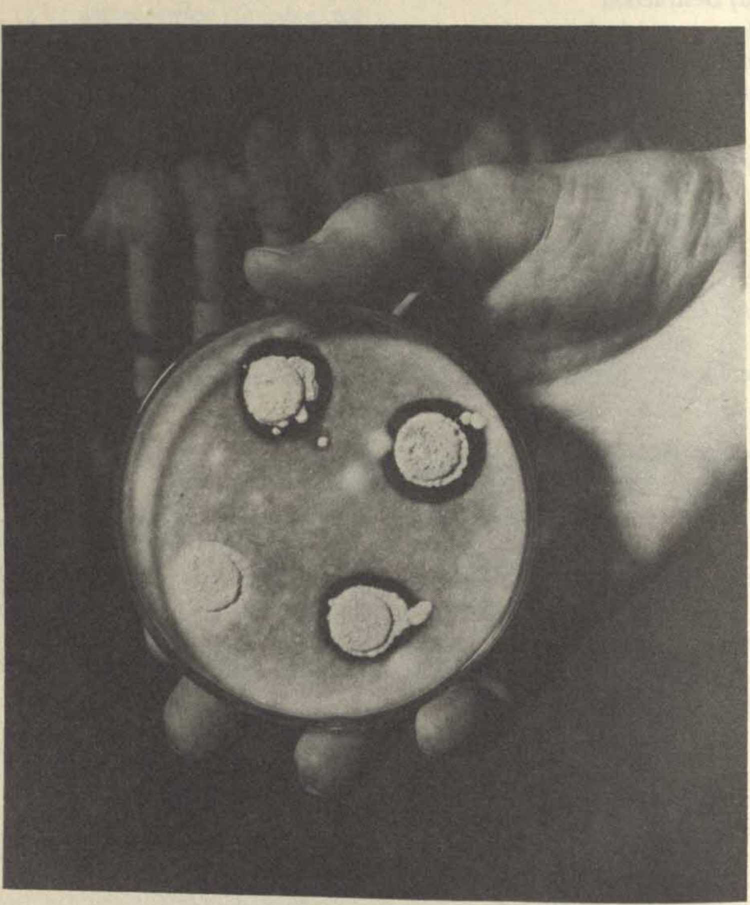
Rot occurs in timber and textile materials due to bacterial action.

Food poisoning occurs due to action of *Salmonella, Staphylococcus* and *Clostridium* bacteria, present in faeces, septic skin infections and soil contaminating fresh and cooked foods.

(i) *Bacterial disease in man*

Pathogenic bacteria cause diseases in plants and animals by producing poisonous toxins. The following are some of the main bacterial diseases in man.

plate 19.2 *a culture of the microbe* Streptomyces rimosus. *Although resembling a fungus mould it is classified as a bacteria. Found naturally in soil, it produces the broad spectrum antibiotic oxytetracycline (Pfizer Ltd)*



(1) Cholera

The source of infection is water and food contaminated with human faeces containing the cholera bacteria *vibrios*.

Symptoms are violent diarrhoea, collapse and dehydration.

It is treated with bacteriostat antibiotics and maintaining fluid balance homeostasis. Prevention is by *vaccination* twice yearly, improved sanitation, clean water supplies and personal hygiene.

(2) Gonorrhoea

The source is from sexual organs of an infected person passed during sexual intercourse, caused by *gonococcus* in mucous membranes in urethra, or uterus of women.

Symptoms are discomfort on micturating in men and yellow discharge from penis, fever and headache. Women show fewer symptoms and may not seek treatment so reinfection of more men may occur.

It is treated with antibiotics in early stages of infection.

(3) Tuberculosis

Between one and two million people die in the world each year from tuberculosis, a disease caused by a *bacillus – Mycobacterium tuberculosis*. The sources are infected humans and cows, who infect others by droplet infection, coughing, spitting, or infected milk. The bacillus attacks *any* human tissue or organ, but the lung is most commonly infected in *pulmonary tuberculosis*.

Symptoms are cough, blood spitting, fever, night sweating and loss of weight.

Treatment is by rest and fresh *air* and antibiotic streptomycin and other drugs. Prevention is by good nutrition, improved personal hygiene, mass X-ray and elimination of tuberculous cows from dairy herds by tuberculin testing. Immunisation with BCG (Bacille Calmette-Guerin) is given to all teenagers in the United Kingdom.

(g) Transmission of pathogenic bacteria

Isolation and quarantine prevent transmission from an infected person or animal to others in a population.

Contact transmits bacteria by *touching* sources of infection, faeces, skin, bacterial cultures, and infected animals. Open wounds can be infected with *tetanus*, lock-jaw, bacteria from soil.

Insect bites: fleas transmit plague and typhus fever; houseflies transmit dysentery; and lice transmit typhus and relapsing fevers.

Droplet infection occurs through coughing, sneezing, spitting and breathing.

Carriers are people who harbour an infectious microbe without ill effects. Most people have staphylococci in the nose, and therefore masks are worn by doctors and nurses. A minority carry diphtheria and typhoid, and if employed as food workers could infect food.

Food and water: foods are media for bacterial growth with the exception of dried and preserved foods. Table 19.1 lists the ways in which food can be preserved.

Table 19.1 *food preservation methods*

Principle	*Method*	*Application*
Heating: coagulates pathogen protein	1 *Pasteurisation*: heating to 70°C for 15 s	Milk and fruit juices. Ice cream and liquid eggs
	2 *Boiling*: heating to 100°C in cooking and stewing	Most cooking methods
	3 *Pressure cooking*: heating to 110°C	Destroys spores. Destroys *Clostridium welchii*. Sterilised milk
	4 *Roasting*: heating above 110°C	Most oven cooking methods
	5 *Canning*: heating to 115–125°C in ovens or pressure cookers	Canned foods sealed in air-free conditions
Refrigeration: slows down pathogen rate of growth	1 Domestic refrigerator: cools to 0–5°C	Short-term storage
	2 Deep freezing: cools to −20 to −30°C	Long-term storage
Dehydration: removes *water* from food, preventing pathogen growth	1 Spray drying	Fruit, coffee, milk, soups, eggs, potatoes
	2 Vacuum drying	Fruit, coffee, milk, soups, eggs, potatoes
	3 Freeze drying	Fruit juice, shellfish, peas, cakes
	4 Tunnel drying	Fruits and vegetables, herbs, spices
Chemical preservatives: prevent growth of pathogens	1 Sugar	Jams, syrups
	2 Salt	Bacon, vegetables, fish
	3 Vinegar	Pickles, sauces
	4 Smoking (phenols)	Fish and ham
	5 Sulphur dioxide	Fruits and fruit juices, potatoes
	6 Various chemicals: benzoic acid, sodium nitrite, sodium nitrate	Ham, bacon, coffee
Radiation: destroys pathogens	1 Ultra-violet rays	Food treatment rooms. Bread and cake shops
	2 X-rays and gamma-rays	Radiating food in manufacture before and after packaging
	3 Microwaves	Part of microwave cooking process

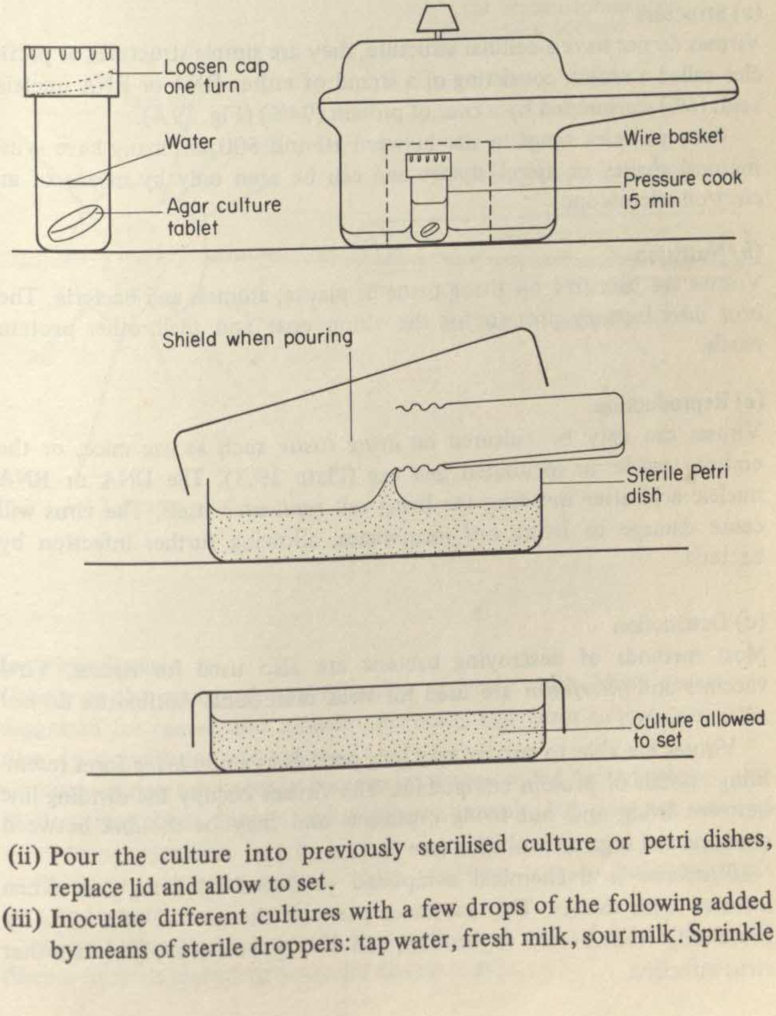
Experiment 19.1 *culture of bacteria* (Fig. 19.3)

WARNING: See Section 19.2 and observe all precautions.

Procedure

(i) Prepare a *nutrient agar* culture using Oxoid tablets (Oxoid Division, Oxoid Ltd, London SE1 9HF – School Microbiology Kit). Place one tablet in 10 cm^3 of water in small screw cap bottle and sterilise in a pressure cooker.

fig 19.3 *apparatus used in preparing a culture media plate*



(ii) Pour the culture into previously sterilised culture or petri dishes, replace lid and allow to set.

(iii) Inoculate different cultures with a few drops of the following added by means of sterile droppers: tap water, fresh milk, sour milk. Sprinkle a little fresh garden soil on one culture. Leave one culture dish *exposed* to room air for 30 min. Tie down all lids with adhesive tape and label.

(iv) Incubate dishes in warm places, i.e. airing cupboards or incubator ovens at 38–40°C for 3 days.

Observations

Bacterial colonies are recognised by their yellow, white, pink glistening appearance.

DISPOSE of all material as in Section 19.2.

19.4 VIRUSES

(a) Structure

Viruses do not have a cellular structure, they are simple structures or particles called a *virion*, consisting of a strand of either DNA or RNA nucleic acids (6%) surrounded by a *coat* of protein (94%) (Fig. 19.4).

Virus particles range in size between 10 and 500 μm; many have symmetrical shapes or spiral shapes and can be seen only by means of an *electron* microscope.

(b) Nutrition

Viruses are *parasites* on living tissue of plants, animals and bacteria. The *host* manufactures protein for the virion coat and their other protein needs.

(c) Reproduction

Viruses can only be cultured on *living tissue* such as live mice, or the embryo inside an incubated hen egg (Plate 19.3). The DNA or RNA nucleic acid after invading the living cell *replicates* itself. The virus will cause damage to living *cell* membranes, allowing further infection by bacteria.

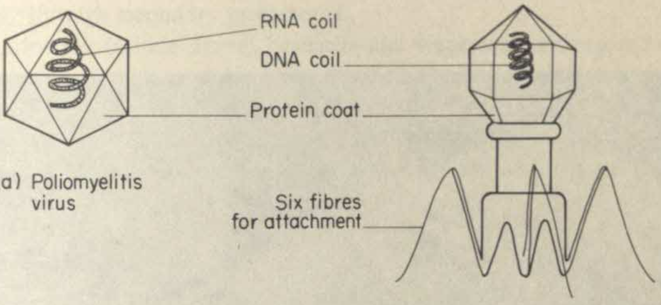
(d) Destruction

Most methods of destroying bacteria are also used for viruses. Viral vaccines and *interferon* are used for virus infections. Antibiotics do *not* affect viruses.

Viruses are able to survive very long periods as a *non-living* form resembling crystals of protein compounds. The viruses occupy the dividing line between living and non-living organisms and may be the *link* between chemical and organic evolution (see Section 17.1).

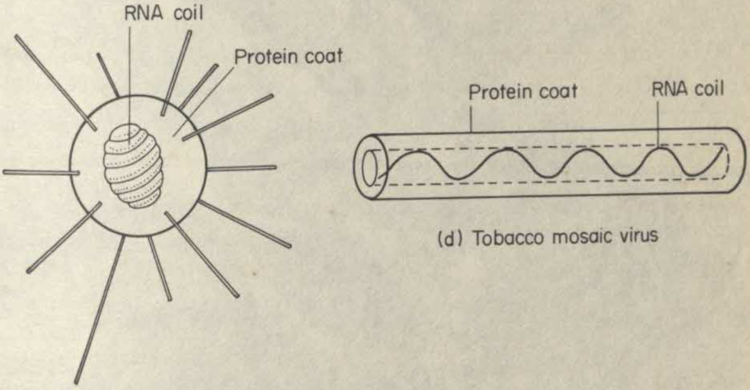
Interferon is a chemical compound produced by living cells when infected with viruses. This substance prevents the growth of a virus by preventing nucleic acid replication, and also gives *immunity* to another virus infection.

fig 19.4 *the structure of various viruses (not to scale)*



(a) Poliomyelitis virus

(b) Bacteriophage virus, kills bacteria



(c) Influenza virus

(d) Tobacco mosaic virus

(e) Virus diseases

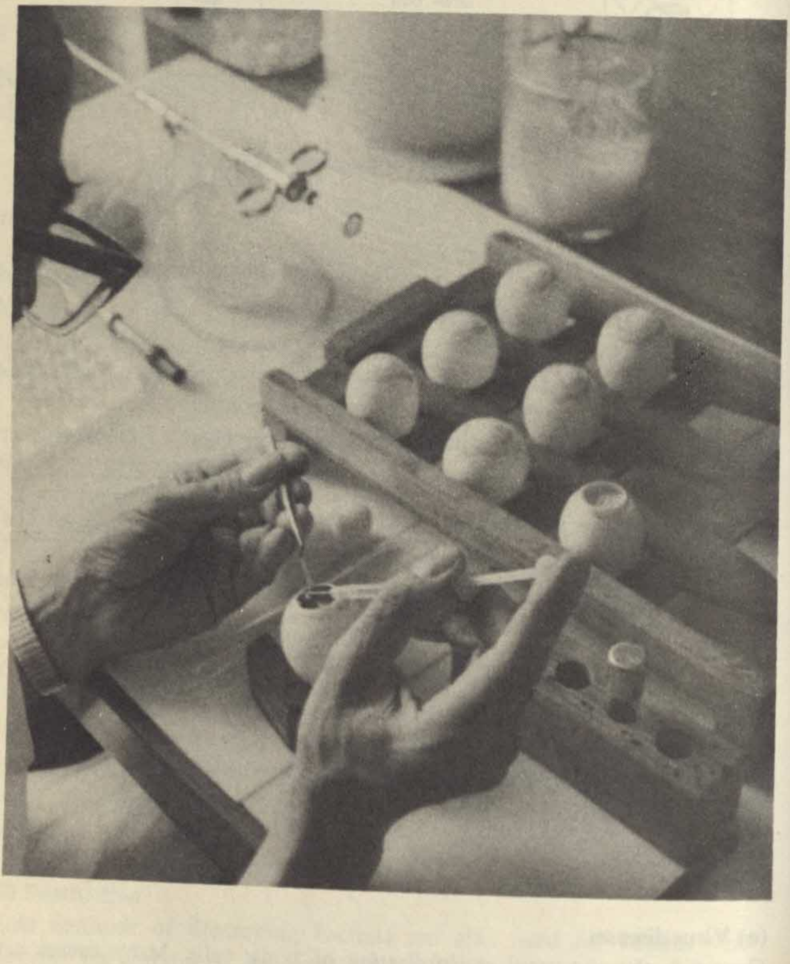
Cancer is the abnormal *multiplication* of body cells. Many causes are suggested for cancer and include chemicals, tars from tobacco smoking, diet, drugs, pollution and viruses.

Virus disease can occur in bacteria by viruses called *bacteriophages*, and in flowering plants, insects and vertebrate animals, but does not occur in other living organisms.

Plant virus diseases include those attacking tomato, tobacco, sugar beet and potato.

Animal virus diseases include *myxomatosis* in rabbits, foot and mouth disease in cattle and swine vesicular disease in pigs.

plate 19.3 *influenza virus being cultured in a living chick embryo (World Health Organisation)*



(i) *Human virus diseases*

These are transmitted by contact, e.g. warts; insect bites from certain species of mosquitos causing yellow fever; droplet infection in influenza and common cold; or food infection causing viral hepatitis and poliomyelitis.

(1) Influenza

Influenza is of three main types; virus A causes epidemics every 2–3 years; virus B causes the *annual* winter flu outbreaks in schools and other institutions; virus C is an infection similar to a common cold. The 1917-19 influenza pandemic due to a virus A caused the death of 20 to 30 M people mainly through secondary pneumonia.

Symptoms include fever, headache and weakness, with infections of air passages. Complications involve bacterial *secondary* infection in cells damaged by viruses, causing pneumonia.

Treatment is limited to preventing bacterial infection with antibiotics. Prevention is by *immunity* from an earlier attack; vaccines are effective against *known* strains of virus.

(2) German measles

German measles, rubella, attacks children and young adults, causing slight fever, rash, swollen lymph glands, throat infection and nasal catarrh.

German measles injures the *embryo* in a pregnant woman causing deafness, eye disorders, heart and liver damage, mental handicap and other disorders, through the virus multiplying in the embryo tissue.

Girls can acquire immunity by immunisation at age 11 to 13 years in the United Kingdom.

(3) Smallpox

Smallpox, Variola major, is a highly infectious virus disease, which has been eradicated by the activity of the World Health Organisation (WHO). Transmission is by contact, the *Variola* virus entering the body by way of the respiratory system.

Symptoms develop as fever, headache and backache, and a *rash* appears on the face, hands and arms. The skin rash turns to spots, blisters, which then become infected with bacteria and form pus-filled pustules (Plate 19.4).

The virus infection can be treated with special *antiviral* drugs, whilst the bacteria infection is treated with antibiotics. Vaccination is given to those travellers who have visited or made contact with smallpox sufferers, from stocks of freeze-dried vaccine.

19.5 FUNGI

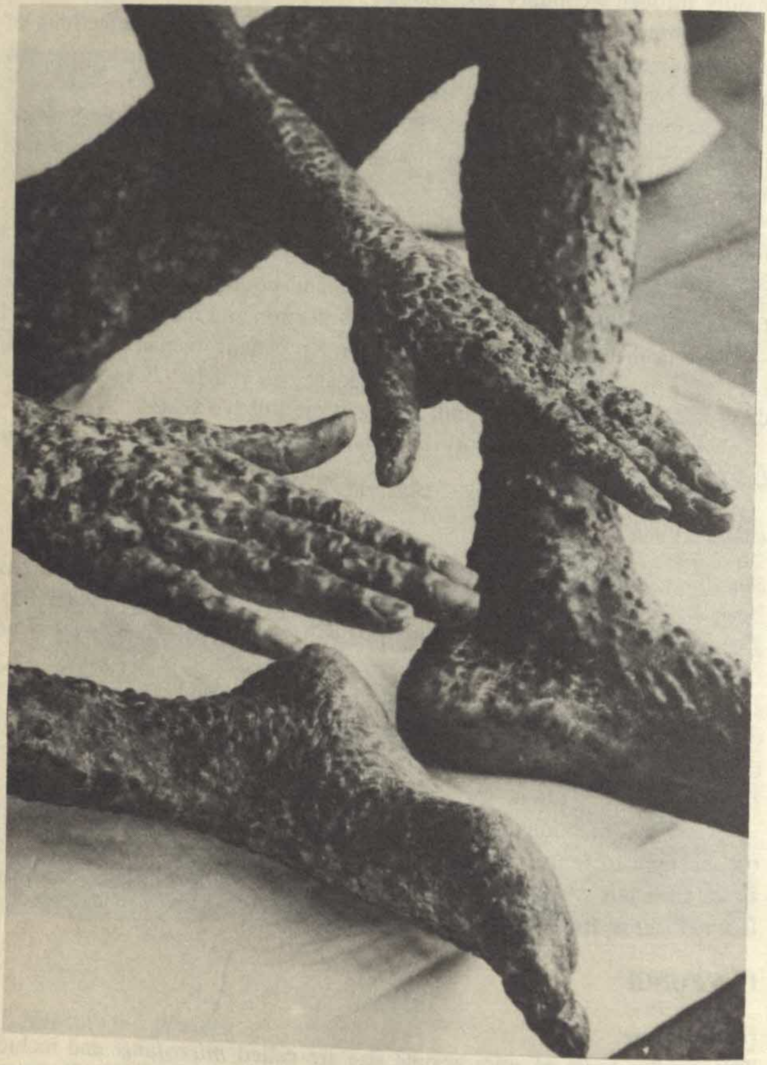
(a) Structure

The smaller fungi of microscopic size are called *microfungi* and include yeasts, moulds, rusts and smuts. The fungus body is composed of thread-like *hyphae* interwoven in a *mycelium*.

(b) Nutrition

Many microfungi are saprophytes or *decomposers* feeding on dead organic matter and responsible for decay and humus formation in soil. *Parasitic* fungi are found on living organisms.

plate 19.4 *the virus disease smallpox,* Variola, *seen as a rash of fluid-filled vesicles on the skin (World Health Organisation)*



(c) Destruction

Heat as dry heat from gas flame torches is used to destroy the dry rot fungus.

Fungicides are different chemicals used to kill fungi.

Antibiotics, nystatin and griseofulvin, are used to treat *fungus* infections of the skin.

(d) Beneficial fungi

Soil fungi are responsible for decomposition.

Antibiotic producers: Alexander Fleming (1881-1955), a microbiologist, discovered the bactericidal enzyme *lysozyme* and the first antibiotic penicillin. Bacteria and fungi can produce antibiotics which are toxic to other bacteria and fungi. *Penicillins* are produced by the microfungus *Penicillium* sp. Other microfungi produce *griseofulvin* and *fumagillin.*

Fermentation is the important process of anaerobic respiration (see Section 10.3) in which *yeasts* produce ethanol and carbon dioxide during dough raising, and in wine, beer and spirit production. Camembert and Roquefort *cheeses* are matured by action of fungal moulds.

Food supplement: yeasts are also valuable sources of vitamins of the B group and protein. *Microbial* protein is produced by feeding certain yeasts (*Fusarium*) with hydrocarbon oil wastes. The yeast growth is harvested and dried to produce a fibrous protein containing 45% protein.

(e) Harmful fungi

Foods and material pests: fungi infect food in store and cause infection of wood, dry and wet rot, and textile materials.

Pathogenic fungi, Trichophyton sp., cause disease seen as *ringworm* of skin, hair, finger and toe nails in man, and *orfe*, an infection of the hide, in cattle (see Plate 18.1).

(i) *Plant fungal diseases*

(1) Powdery mildew disease

This is caused by the parasitic fungus *Erysiphe* found on grasses, cereals, peas and swedes (Fig. 19.5). Spores (Section 15.2) called *conidia* are carried by air currents to infect closely planted populations, and land on leaves germinating into a white powdery mycelium. *Haustoria* penetrate the leaf epidermis to obtain water and nutrients.

Treatment is by spraying with a copper and sulphur *fungicidal* mixture.

(2) Potato blight

This is caused by the parasitic fungus *Phytophora* attacking the leaves of potato plants (Fig. 19.6). Spores germinate to form a mycelium with *haustoria* secreting enzymes to digest leaf cell contents. A hypha emerges from the leaf producing spores rapidly distributed by air currents to infect neighbouring plants.

Control is by fungicidal spraying, and burning of infected haulms. Certain potato varieties are genetically *resistant* to blight.

The potato blight caused the Irish famine of 1845 in which over 1 M people died of starvation.

fig 19.5 *the life-cycle of powdery mildew mould,* Erysiphe *sp., on a wheat leaf*

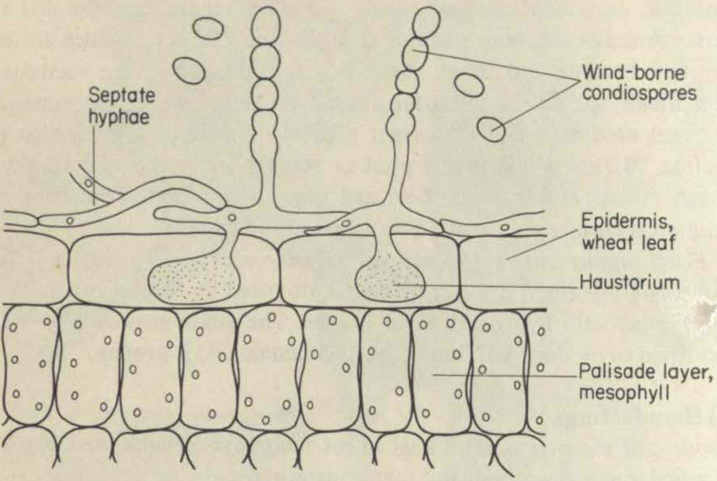
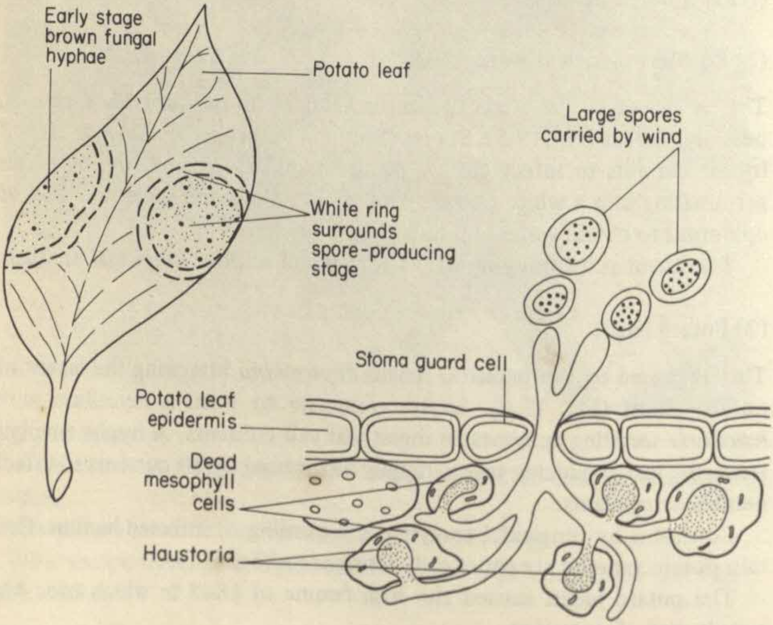


fig 19.6 *the potato blight fungus,* Phytophora infestans, *on a potato leaf*


Early stage brown fungal hyphae
Potato leaf
White ring surrounds spore-producing stage
Large spores carried by wind
Stoma guard cell
Potato leaf epidermis
Dead mesophyll cells
Haustoria

Experiment 19.2 *culture of microfungi*

SEE precautions – Section 19.2

Procedure

(i) Prepare a potato or malt agar culture using Oxoid tablets.
(ii) Inoculate the culture by rubbing a sterile wire loop on mould growth on fruit, jam or old leather. Sprinkle a little garden soil onto another culture.
(iii) Incubate in a warm place at 38-40°C for 2-3 days.

Observations

Note the white thread-like appearance of the mycelium and observe the dark spore-producing *sporangia*.

19.6 PROTOZOA

The unicellular protozoa are parasites responsible for malaria, sleeping sickness and amoebic dysentery.

(a) Malaria

Malaria is one of the commonest causes of death in the world. Sir Ronald Ross (1857-1932), a physician, proved that malaria was transmitted by the mosquito, *Anopheles* sp. The parasite responsible for malaria is the protozoon *Plasmodium.* It requires *two* hosts to complete its life-cycle (Fig. 19.7).

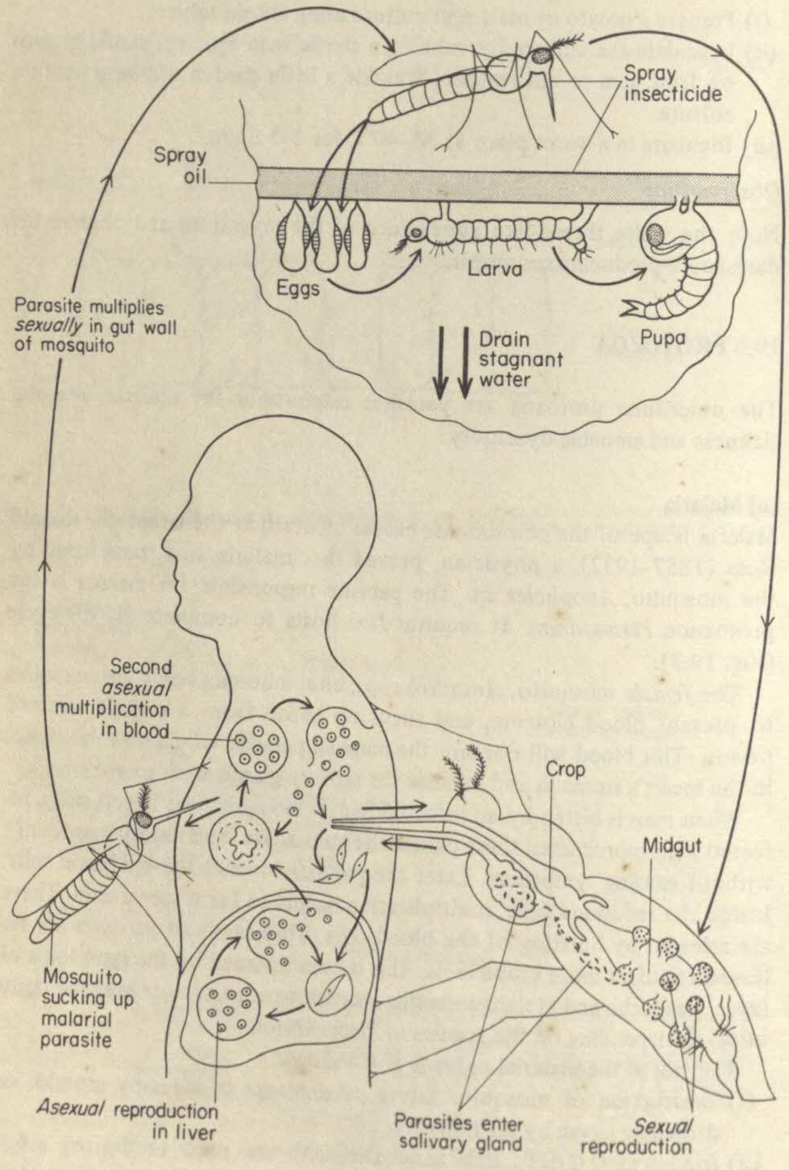
The *female* mosquito, *Anopheles* sp., bites a human being, inserts saliva to prevent blood clotting, and sucks up blood from a malaria infected person. This blood will contain the malarial parasite which now multiplies in the insect's stomach and invades the salivary glands with *sporozoites*.

When *man* is bitten by an infected female mosquito she injects saliva infected with *sporozoites*; these pass to the human liver and multiply *asexually* without causing symptoms. Later the parasite invades the red blood cells. Inside the red blood cells, multiplication occurs to form *merozoites*. These are released by bursting of the blood cells. Thousands of parasites are released to infect more blood cells. This is accompanied by the symptoms of fever, headache and violent shivering, occurring at regular or irregular daily intervals depending on the species of *Plasmodium*.

Control of the malarial parasite is as follows:

(i) Destruction of mosquito larvae by *drainage* of swampy ground, or drowning larvae by *oil spraying*.
(ii) *Insecticides* (DDT, BHC and Dieldrin) are used to destroy *adult* mosquitoes. Some mosquitoes are becoming *resistant* to insecticides.

fig 19.7 *outline of the mosquito,* Anopheles *sp., life-cycle, and the transmission and life-cycle of malarial parasite,* Plasmodium *sp., in man*


Spray insecticide
Spray oil
Eggs
Larva
Pupa
Drain stagnant water
Parasite multiplies *sexually* in gut wall of mosquito
Second *asexual* multiplication in blood
Crop
Midgut
Mosquito sucking up malarial parasite
Asexual reproduction in liver
Parasites enter salivary gland
Sexual reproduction

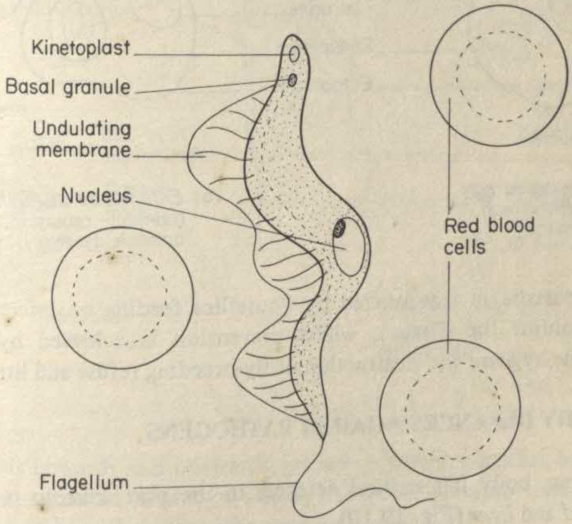
(iii) *Malarial drugs* (chloroquin, proquanil, primaquin and quinine) kill or suppress the parasite in the blood or liver. Chloroquin added to table salt is a preventative treatment in malarious areas.

(iv) *Sickle cell trait* people have a natural resistance to malaria (see Section 17.8).

(b) Sleeping sickness

This is an infectious disease caused by the protozoon blood parasite *Trypanosoma* (Fig. 19.8), widespread in tropical Africa and found in the blood of human beings, cattle, pigs and horses.

fig 19.8 *the sleeping sickness parasite,* Trypanosoma *sq., a protozoon animal*



The parasite has a single flagellum and feeds on blood plasma fluid. The Tse-tse fly (Plate 2.1) bites a human being, injecting the parasite which is obtained from other infected human beings or reservoirs in infected cattle.

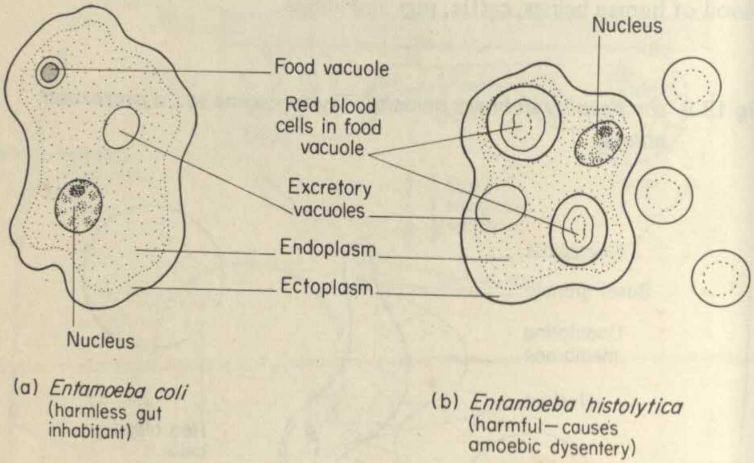
Symptoms of infection are variable, including lack of appetite, sleepiness or being agitated, with fever. The central nervous system is affected.

The disease is curable in the early stages by drugs which include compounds of arsenic. Prevention is by eradication of Tse-tse fly breeding grounds with insecticides or burning the vegetation.

(c) Amoebic dysentery

This is caused by a protozoon *Entamoeba* (Fig. 19.9) which enters the digestive tract by way of contaminated water and unwashed fruit, vegetables and salad. The parasite multiplies in the large intestine, causing ulceration of the epithelium, and severe diarrhoea, with bleeding.

fig 19.9 *(a) the harmless human gut parasite,* Entamoeba coli *and (b) the harmful dysentery amoeba,* Entamoeba histolytica



(a) *Entamoeba coli* (harmless gut inhabitant)

(b) *Entamoeba histolytica* (harmful—causes amoebic dysentery)

The parasite is transmitted by houseflies feeding on infected faeces. Drugs control the disease, whilst prevention is achieved by personal and public hygiene and destruction of fly-breeding refuse and litter.

19.7 BODY DEFENCES AGAINST PATHOGENS

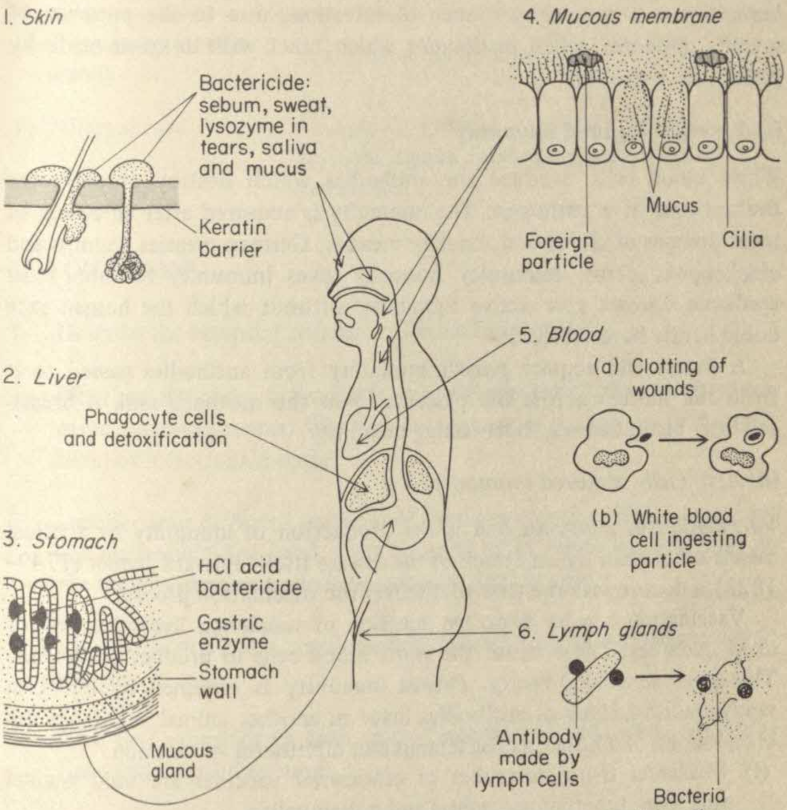
The human body has natural defences in the *skin*, *mucous membranes*, the *blood* and *liver* (Fig. 19.10).

(a) Skin

The skin (see Section 12.9) is a barrier against mechanical and chemical injury, being composed of a tough, almost impermeable layer of keratin. *Bactericides* are secreted in sweat, sebum and tears from glands associated with the skin.

(b) Mucous membranes

Mucous membranes lining the mouth, nose, lungs and gut secrete *mucus*. The respiratory mucous membrane has a *ciliated* epithelium which wafts fig 19.10 *the natural body defences against infectious disease*



the mucus upwards and outwards, gathering foreign particles, bacteria and dust to be expelled in phlegm and by the nose. Tobacco smoke contains *nicotine* which paralyses the cilia, preventing their action.

The stomach mucous membrane secretes gastric juice containing hydrochloric acid which has a disinfecting bactericidal action. Vomitting and diarrhoea are means of eliminating harmful toxic materials.

(c) Blood and liver

Phagocytes are present in blood as the white blood cells and lymphocytes (see Sections 9.6 and 9.12).

Liver has defensive *macrophages* with a phagocytic action. In addition the liver is able to *detoxify* poisonous substances, drugs, etc., from the blood, which could accumulate in the body (see Section 12.2).

(d) Immunity

Immunity is a means of defending the individual and the community. *Immunity* is a natural resistance to infection, due to the presence of specific antidotes called *antibodies* which react with *antigens* made by pathogenic microbes.

(i) *Naturally acquired immunity*

White blood cells produce the antibodies which destroy or neutralise the antigens of a pathogen. The immunity is acquired after an attack of most diseases of childhood, namely measles, German measles, mumps and chickenpox. *Active* immunity normally gives immunity for life. Most epidemic diseases give active immunity without which the human race could hardly have survived.

A *foetus* will acquire *passive* immunity from antibodies passed to it from the mother across the placenta or in the mother's milk if breast-fed after birth; this is a short-lasting immunity.

(ii) *Artificially acquired immunity*

Vaccination or *immunisation* is the production of immunity by artifical means other than by an attack of the disease itself. Edward Jenner (1749-1823), a doctor, was the first to discover the vaccination process.

Vaccination can be done by injection of *weakened* live microbes, or *dead* microbes. These cause the white blood cells to produce antibodies. This gives *active* immunity. *Passive* immunity is obtained by injecting ready-made vaccines of antibodies made in another animal, e.g. from the blood serum of a horse, as for tetanus and diphtheria vaccination.

(i) *Weakened* living microbes or *attenuated* vaccines are used against smallpox, tuberculosis, rabies and poliomyelitis.
(ii) *Dead* microbes are used in vaccines against cholera, influenza, typhoid and whooping cough.

The following is an immunisation schedule for children, and travellers abroad, used in the United Kingdom.

Age	*Immunisation*
3–6 months	Diphtheria, tetanus, whooping cough
6–8 months	Diphtheria, tetanus, whooping cough, oral polio
4–6 months later	Diphtheria, tetanus, whooping cough, oral polio
15 months	Measles
On starting school	Diphtheria, tetanus, polio boosters
10–13 years	Tuberculosis, BCG vaccination, unless immune
Girls 10–13 years	German measles (*rubella*)

Age	Immunisation
15–19 years on leaving school	Tetanus and polio boosters
Travellers abroad	Cholera x2, typhoid x2, yellow fever x1, hepatitis human antibodies, depending on destination.

19.8 QUESTIONS

1 Describe the essential conditions for bacterial growth.

2 What are the main natural defences of the human body against pathogenic micro-organisms? What are the sources of drugs used in the treatment of infectious disease?

3 Describe four different methods of food preservation. Which organisms are responsible for food going bad and what effect has this food on the body? Give five important rules for food handlers.

4 Describe how viruses require other higher living organisms in order to survive.

5 Give two examples in each case of micro-organisms which are beneficial and harmful to man.

6 Describe one named pathogenic disease in man, its cause and method of infection and control.

CHAPTER 20

MAN AND THE EXTERNAL ENVIRONMENT

20.1 MAN'S POPULATION

Modern man is called *Homo sapiens* and has been on Earth for about 40 000 years, having evolved from a common ancestor which he shared with *Olduvai, Java, Peking* and *Neanderthal* man, now extinct (Plate 20.1).

Early man had a *niche* in the ecosystem as a *primary* consumer feeding on roots and fruits, and later became a *secondary* consumer and predator in hunting and killing his *prey*. As man evolved, he *changed* his niche in the ecosystem.

Communities of plants and animals were progressively *modified*, by man, partly by his use of *fire* to clear grasslands and in his *cultivation* of plants and in animal *husbandry*. Man was learning how to alter and *manipulate* the ecosystem in which he lived.

No longer himself the prey of other predators, and with increased availability of food, the numbers of his species or *population* increased. From time to time the population was decreased by famine, food shortage, disease, climate and competition for territory.

(a) Characteristics of populations

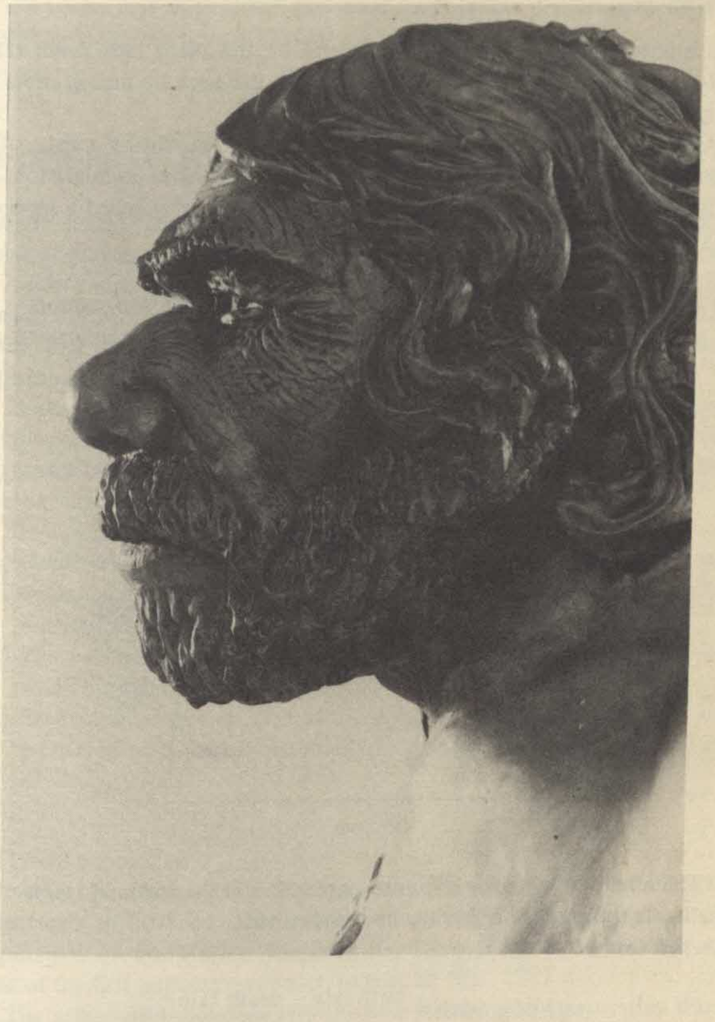
Populations of human beings share the following main characteristics with other populations of living organisms.

(i) *Distribution*

This is the *area* occupied by the population. Man is distributed in different countries. Man's distribution is determined by population *census* and is part of the study of *demography* or numerical study of populations.

(ii) *Density*

This is the number of individuals in a certain area, e.g. number per square kilometre (km^2). Towns will have a greater population density than the plate 20.1 *Neanderthal man,* Homo sapiens neanderthalensis, *who lived in Europe over 40 000 years ago and spread into North Africa and Western Asia (Bayer Chemical Co. Ltd)*



countryside, whilst some countries have greater population densities than others. Parts of Europe and Asia have over 100 inhabitants/km^2, whilst Greenland has less than 1/km^2.

(iii) *Birth rate*

This is the number of *live* births per 1000 of a human population per year.

(iv) *Death rate*

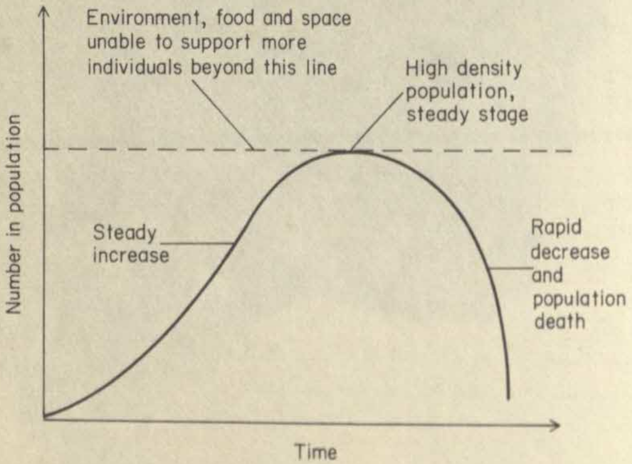
This is the number of deaths per 1000 in a human population per year.

(v) *Growth*

The numbers in a population will depend on the birth rate, death rate, and also on the numbers who enter or leave the area by immigration or emigration.

Growth can be measured for populations and shown by means of a *graph*. The graph for growth of a population without immigration or emigration (Fig. 20.1) will have an S shaped curve, also called a *sigmoid curve* (see also Section 11.7 and Fig. 11.13).

fig 20.1 *population graph for a population of organisms, for example bacteria growing on an agar plate in a restricted environment*



The *rate of growth* for a human population is the birth rate *minus* the death rate (both per 1000) with the answer divided by 10. This is measured as a *percentage*:

$$\text{rate of growth} = \frac{\text{birth rate} - \text{death rate}}{10}\ (\%)$$

For example, the birth rate in a country is 17.6 and its death rate 9.6; therefore its growth rate is

$$\text{growth rate} = \frac{17.6 - 9.6}{10} = \frac{8}{10} = 0.8\%$$

(vi) *Doubling time*

This is the number of years to double present populations, assuming the growth rate remains the same. The doubling time for the world population is 38 years, that is in 2013 the world population will be near 8000 M (1975 population under 4000 M).

20.2 THE HUMAN POPULATION EXPLOSION

Human *culture* commenced over 5000 years ago, leading to the development of industry, technology and modern medicine in the *last* 200 years.

Modern man was able to modify his external environment by building *homes* to live in, making *clothes* to wear, and releasing *heat* energy from fossil fuels so the physical environment would not affect him and making it possible to live in almost any climate.

Modern man has become a *producer* able to synthesise complex organic compounds from simpler chemical compounds; a *consumer* of other living organisms and mineral resources, and a *decomposer* by means of combustion or burning of whatever he considers is of no value to him.

Modern man has affected the ecosystem in the following ways:

(i) *Other living organisms* have been increased in certain plant and animal *crops*, and decreased or made extinct by hunting, fishing, or exterminated as *pests*, *predators* or *parasites*.

(ii) *The habitat* has been destroyed by land clearance, removing woodlands, grasslands, hedges and soil.

(iii) *Ecosystem processes* such as the natural cycling processes have been interfered with, which has resulted in pollution of water, land and air.

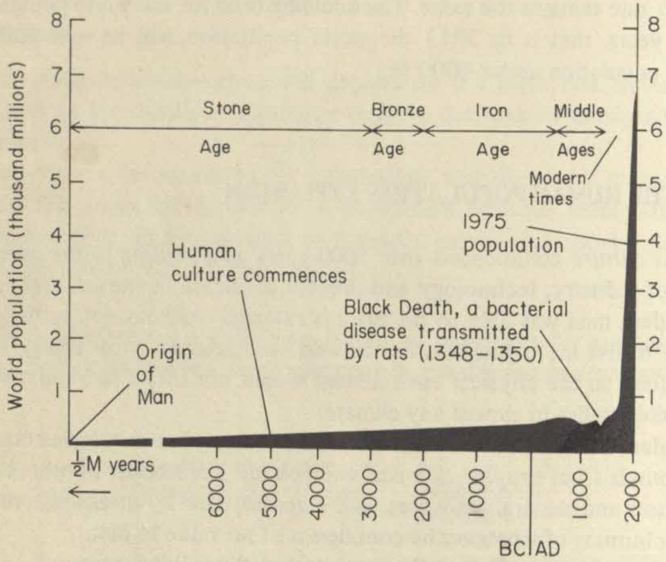
(a) World population

The *world* population (Fig. 20.2) at present is about 4000 M, *double* the population of 50 years ago, and *four* times that of 200 years ago. The population of the United Kingdom has risen from 12 M in 1801, the year of the first population *census*, to near 55 M in 1981.

The projected population growth graph for the world population shows a steep rise in the first part of the S shaped curve, and has *not* reached the point of levelling or the *limit* for world population.

Table 20.1 summarises the human population distribution, density, growth rate and doubling times for different world *regions*. A comparison is made for the United Kingdom and New Zealand, countries of approximately equal *area*.

fig 20.2 *population graph for man from earliest time (figures prior to 1825 are estimated)*



(b) Developed and underdeveloped countries

An *underdeveloped* country is one which has not fully developed its agricultural and industrial *resources* to the full. They are countries with an *expanding population*, a *high*-density population for example in India and Egypt, or a *low*-density population in Brazil and Chile.

The *developed* countries have a *stable* population with low natural increase, and may have a high-density population as in the United Kingdom and Japan, or a low-density population as in Canada and New Zealand.

Table 20.2 compares some features of developed and underdeveloped countries.

(c) Some reasons for the world population increase

Decrease in infant death rate

The infant mortality rate is the number of deaths amongst children under one year old per 1000 born. In the United Kingdom in 1845 the rate was 145 children dying under one year old out of every 1000 born. Today the rate is 13 per 1000, a reduction of over 90%.

Table 20.3 summarises reasons for world population increase and indicates the consequences of continued increase at the present growth rate. Methods of human population control are shown.

Table 20.1 *human population*

	Description	*World region*	*World*	*UK**	*New Zealand**
Population (measured in millions)	*Number* of people of different ages, freely interbreeding in a definite *area* (country) at the same *time* (Census figures can be unreliable for some countries) *Demography* is the numerical study of populations	Asia, 56%; Europe, 12%; Africa, 9%; Latin America, 8%; USSR, 7%; North America, 6%; Oceania (Australia, etc.), 0.5% 1 Half the human population lives in Asia 2 One in four people are Chinese	4000 M	55 M	3 M
Density (measured in people per square kilometre)	*Number* of people per unit area, ratio of population to a land area	Europe, 94/km^2; Asia 75/km^2; Latin America, 14/km^2; North America, 11/km^2; Africa, 11/km^2; USSR, 11/km^2; Oceania, 2/km^2 1 Some countries are over-populated 2 Population density varies within a country – more in *towns* than in *villages*	27/km^2	220/km^2	10/km^2
Growth rate (measured as a percentage difference in birth and death rate)	*Death rate* is number of deaths per 1000 per year *Birth rate* is number of live births per 1000 per year *Rate of growth* is $\frac{\text{birth rate} - \text{death rate}}{10}$	Latin America, 3%; Africa, 2.5%; Asia, 2.3%; Oceania, 2.1%; North America, 1.3%; USSR, 1.1%; Europe, 0.8% 1 Certain countries have *expanding* populations 2 Others have *stable* populations	1.8%	0.1%	1.4%
Doubling times (measured in years)	Number of years to *double* the present population (Figures assume the growth rate is constant)	Latin America, 24 yr; Africa, 28 yr; Asia, 30 yr; Oceania, 33 yr; North America, 52 yr; USSR, 63 yr; Europe, 87 yr	38 yr	between 150 and 690 yr	50 yr

*Countries of almost equal land areas.

Table 20.2 *a comparison of developed and underdeveloped countries*

	Developed countries	*Developing countries*
Examples	UK, USA, USSR	Latin America, India, Africa
Natural resources	Industry and resources fully developed	Resources not fully developed. Mainly agricultural
Growth rate	Low	High
People aged under 15 yr	Low proportion of population	High proportion of population
Life expectancy	High (average 70 yr)	Low (29 yr in Borneo)
Population density	1 High in UK and Belgium 2 Low in New Zealand and Australia	1 High in India, Cuba and Indonesia 2 Low in Mexico and Brazil
Food intake	Adequate for a *balanced* diet for 40% of world population. One-third of world population consumes three-quarters of world's food supply	Inadequate for a *balanced* diet. 50% of world population suffer *malnutrition*, 10–15% suffer from *hunger*. Two-thirds of population consumes one-quarter of world's food supply
Income level	Have *high* income	Have *low* income. 50% of world population live in dire *poverty*
Literacy	High standard of literacy and education	Low standard of literacy and education. 35% of the world is illiterate
Main cause of death	Heart disease, cancer and stroke	Infectious disease, diseases in infants, and lung disease

Table 20.3 *the human population crisis*

Reasons for world population explosion	*Consequences of further world population increase*	*Methods of human population control*
Infant mortality rate is number of infant deaths under *one year old* per 1000 born. UK 1840 rate was 145 per 1000 UK 1978 rate was 13 per 1000 a reduction of 90%, achieved by: 1 Disease prevention: medicine, public, personal and food hygiene 2 Improved nutrition: by efficient agriculture 3 Housing and living standards improved 4 Child care, maternity, parentcraft and welfare services 5 Smaller families: two children to a family	1 Resources consumption, minerals, food, timber and fuels 2 Soil production decrease by erosion, pests, etc. 3 Pollution of air, water and soil by toxic waste 4 Overcrowding – less living space, consequences of epidemic disease, crime, violence and social disease 5 Starvation through lack of sufficient food. Populations will outstrip food supply 6 Destruction of the countryside, plants and animal wildlife	1 *Natural checks*: (a) Diseases, black death, cholera, influenza, malaria. Epidemics killed over 40 M (b) Famine, in India, Ireland and China, killed over 22 M (c) Wars: World Wars I and II killed 30 M (d) Earthquakes killed 1½ M in India (e) Nuclear bomb, 80 000 died 2 Contraception (a) Infanticide – killing the baby at birth (b) Abortion – killing baby before birth (c) Sterilisation of male and female (d) Fertility control by 'pill' (e) Caps, condoms, creams, coils – halting sperm (f) Abstinence

20.3 MAN AND AGRICULTURE

To grow crops and provide grazing for animals, *natural* forests were cleared by cutting and the timber used for fuel or as construction material. The *exposed topsoil* lacked protection provided by the tree foliage in deflecting the rain and wind. Streamlets of rain water became gulleys on sloping land, and washed the soil away to collect as silt in rivers.

Grazing animals would cause the loose soil to be compacted, thus facilitating the *capillary rise* of water through the finer soil air spaces, causing it to dry out rapidly and be blown away as dust.

Agricultural *practices* developed which were aimed at preventing soil erosion and improving soil fertility to the advantage of the farmer by *increasing crop yield*.

(a) Ploughing

A hard *compacted* soil encourages water loss by capillarity, and roots are unable to obtain oxygen from air spaces or soil water. Ploughing *aerates* the soil, prevents water loss by capillary rise, and improves soil drainage.

Ploughing along the contours of sloping land produces miniature *terraces* which prevent soil loss by water erosion.

The *freezing* of water in the soil air spaces helps to break up large soil lumps. Soil *pests* are exposed to predators, and leached minerals are brought up from lower levels, and organic matter ploughed into lower levels for decomposition.

Rolling a soil will compact it after seed sowing to bring water to the surface by capillary rise, and encourage germination.

(b) Liming

This is the addition of chalk or lime to correct acidity in soils, and flocculates clay soil by aggregating soil particles and improving aeration and drainage.

(c) Fertilising

This is the method of returning certain soil nutrients removed from soil by the crop or *leached* mainly as soluble nitrates and potassium ions by rain water drainage. Table 20.4 compares organic and inorganic fertilisers.

(d) Crop rotation

This is the method of rearing a *different* crop over a rotational cycle on the *same* land area. In the first year shallow rooting cereal crops such as wheat are grown, followed in the second year by deeper-rooting root crops, for example potatoes. In the third year barley or oats may be grown, Table 20.4 *comparison of organic and inorganic fertilisers*

	Organic fertiliser	*Inorganic fertiliser*
Example	Brown or farmyard manure (faeces and urine, straw). Green manure – clover. Fishmeal, dried blood, compost, sewage sludge, crop residues	Sulphate of ammonia, superphosphates, basic slag, and various mixtures of nitrogen, sulphur, phosphorus and potassium compounds
Composition	*Variable* composition of most elements for plant growth. May not suit a particular crop in being deficient in some nutrients	*Constant* composition. Mixtures made up to suit crop. Highly concentrated form of mineral nutrients
Cost and convenience in use	Sticky and bulky, difficult to load and spread. Cheap	Easy to load and spread. Expensive
Soil condition	Soils improved by *humus* content, moisture holding and source of nutrients. Beneficial to earthworms	Affects soil condition – 'crumb' and mineral balance. No humus content. Harmful to earthworms
Action	Slow decay and release of nutrients. Not easily leached	Rapid release of nutrients. Easily leached causing 'eutrophication' of nearby rivers and lakes (Section 20.6)
Consumption	Decreasing use with dumping of *slurry* on soil surface	Increasing use of chemical fertilisers *eight* times the quantity used in 1950 in the United Kingdom

followed in the fourth year by clover which fixes soil nitrogen by its root nodules and is ploughed in to increase the soil fertility (Fig. 18.16).

The different crops extract different nutrients at different depths.

Weeds are kept down by the crop, and diseases such as potato blight are unable to establish themselves as the same host is not present in the ground each year.

Manuring is not required each year, and inorganic fertilisers are used in smaller amounts to suit the particular crop. Green leguminous manure increases the humus content and reduces the use of *expensive* nitrate fertiliser. It is also *fodder* for grazing animals.

Rotated *grazing* of animals will provide an even distribution of *mulch* manure or excreta.

(e) Monoculture

This is the rearing of the same crop on the same land area each year. A single crop requires less manpower by using mechanised methods of planting and harvesting.

The same crop extracts the same nutrients at the same depth, and consequently the same mixture of inorganic fertiliser will be provided.

Straw and other crop residues will be burnt or sold off instead of providing humus and chemical elements by decomposition. The straw would provide gums to aggregate soil particles and soils lacking humus erode easily. A high *transpiration* rate of a single crop dries out the soil.

The single crop attracts an equally large population of *pests*, as weeds, insects or disease; this requires intensive use of *pesticides* and *herbicides*. The niches or organisms in the ecosystem are disturbed, and diseases establish themselves strongly in the soil.

Monoculture also applies to animals, particularly sheep repeatedly grazed on the same land, or pigs and poultry reared indoors by factory farming methods. Parasites, diseases and pests will establish themselves in such populations, and the animals will need frequent dosing with *pesticides* and *antibiotics*.

20.4 PESTS

Man classifies living organisms into those which *he* considers are *useful* for food, for clothing, as pollinators and which provide pleasure as pets or in sport; and those which are *pests*.

Pests can be harmless organisms which increase in numbers only through man's activities, mainly through monoculture, in competing with him for certain resources; parasites are the *harmful* pests.

(i) *Predators* and *consumers* include locusts (Plate 20.2), aphids, spiders, wasps, cockroaches, rats, mice, pigeons and crows.
(ii) *Vectors* of disease include mosquito, housefly, flea and louse.
(iii) *Pathogenic organisms*, mainly certain bacteria, viruses, fungi and protozoa, cause disease in man and his crops.
(iv) *Weeds* are harmless plants growing in the wrong place, *competing* with the crop for water, nutrients and light.

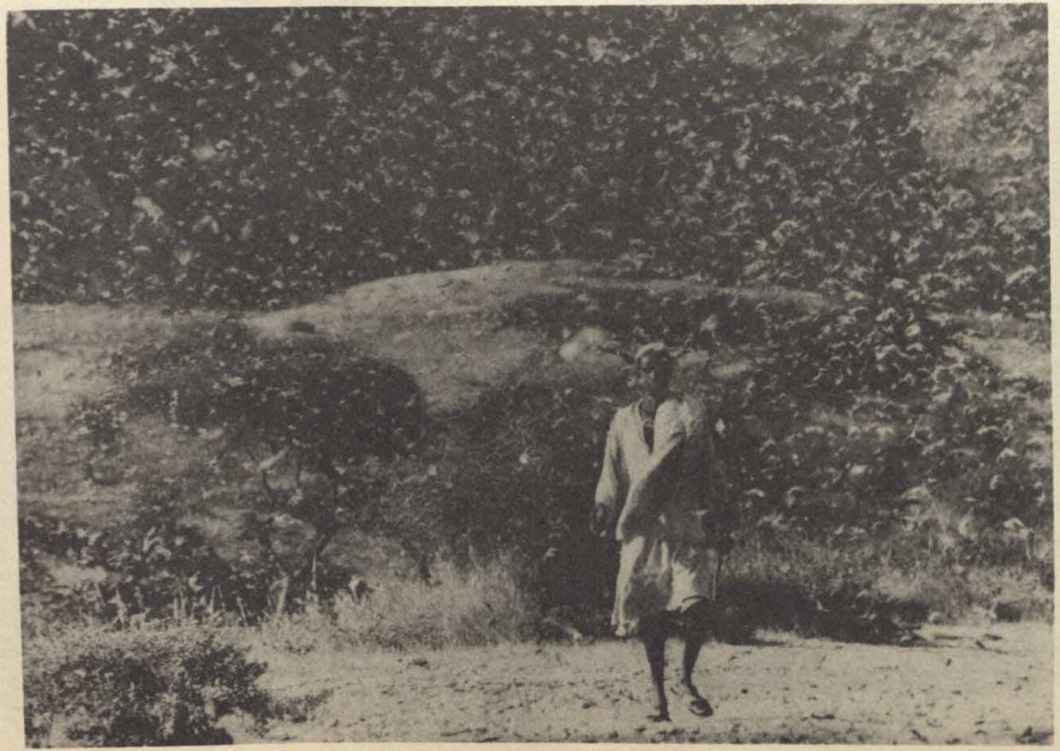
High-density populations as in *monoculture* of plants, animals or human beings will attract other organisms to compete with them for food, nutrients, water, light and other resources, as either *pests* or *parasites*.

The following are the three main methods of pest control.

(a) Biological control

This is the eating or weakening of one species by another, in a *predator/prey* or *parasite/host* interrelationship.

plate 20.2 *millions of locusts,* Locusta *sp., devastating vegetation (World Health Organisation)*



Viruses have been used to control rabbits by myxomatosis, and sawflies on Canadian pine trees reduced by using a virus.

Bacteria have been used to control cabbage white butterfly by spraying with a solution of the bacteria in water.

Fish which eat the mosquito larvae are introduced into mosquito breeding areas.

Cats introduced to New Zealand to reduce rabbits, in turn exterminated the flightless birds.

Insects have been widely used as biological controls. A cactus plant, the prickly pear, introduced to Australia, rapidly spread as a weed. Caterpillars of certain Mexican moths were introduced as controls; these larvae tunnelled through the cactus plants and reduced the cactus population.

California orange and lemon groves were infected with certain scale insects; these were reduced by introducing an Australian insect similar to a ladybird which fed on the scale insect larvae and adults.

(i) *Features of biological control*

(i) Biological control does not usually *eliminate* the pest completely.
(ii) The control takes many years to establish itself.
(iii) The method is partly specific in controlling *one* species.
(iv) Initial research is long and expensive.
(v) It is not *toxic* to man and other organisms.

(b) Chemical control

Chemicals collectively called pesticides will *kill* living organisms. Of the total pesticides used, 54% are *insecticides*, killing insects, 36% are *herbicides*, killing weeds, and 10% are *fungicides*.

Insecticides: rapidly decomposed insecticides include the natural plant products, *derris* dust and *pyrethrum* powder. Long-acting insecticides include the *organochlorine* compounds DDT, BHC and Dieldrin. These have a very persistent effect and are *not* decomposed, remaining in the ecosystems indefinitely. *Organophosphorus* compounds, Parathion and Malathion, are *short*-acting and *non*-persistent, but are highly toxic to human beings.

Herbicides include the plant growth hormones, auxins (see Section 11.9), and the highly toxic Paraquat.

(i) *Features of chemical pesticides*

(i) They are *rapid acting*, and some are instantaneous killers.
(ii) They are *reliable* and easy to apply.
(iii) They destroy *all* pests without selection, killing the harmful and harmless and the pest's *natural* enemies or predators.

(iv) Pests have developed heritable *resistance* to pesticide, for example DDT-resistant mosquito and housefly, and 'super'-rats resistant to rodenticides (Section 17.9).

(v) *Ecosystem balance* is upset by destruction of ecological niches.

(vi) *Pollution* of food, water and air occurs.

(vii) They are *toxic* to man and suspected as causing cancer.

(ii) *Pesticides in food chains*

The *persistent* organochlorine pesticides which do not decompose in the soil have the property of *accumulating* in the fatty tissues of animals.

Persistent pesticides are sprayed on crops from the *air* by aircraft; in this way pesticides are carried *worldwide* by spray drift, to pollute fresh water and sea water.

Sea water contains substantial amounts of persistent pesticides such as DDT; these will enter the *primary* consumers, the zooplankton in the food chain (see Section 18.8). Marine zooplankton *concentrate* the persistent pesticide in their fatty tissues and may have up to 0.04 parts per million (ppm) of DDT.

Shrimps feeding on the zooplankton concentrate the DDT up to *four times* or 0.16 ppm in their fatty tissues. Fish feeding on the shrimps can have fatty tissue DDT concentrations up to *eight* times that of the shrimp, whilst gannet birds feeding on the fish have DDT fatty tissue concentrations almost 50 times that of the fish, and nearly 2000 times the DDT in the tissue of the first in the food chain, namely the zooplankton.

	Zooplankton		*Shrimp*		*Fish*		*Gannet*
DDT concentration (ppm) in fatty tissue	0.04		0.16		1.33		75.5
Ratio	1	:	4	:	33	:	1890

Persistent pesticides will therefore *accumulate* along the food chain, reaching *highest concentrations* in those organisms at the top of pyramids of biomass, e.g. terns, ospreys, herons, cormorants, gulls and kingfishers. Golden eagles are now greatly reduced in numbers due to accumulating persistent pesticides weakening the egg shell and killing off young birds before hatching.

(c) Combined or integrated control

This involves the use of *chemical* pesticides *and* a *biological* control. The method is used for control of red spider mite on tomatoes grown in greenhouses.

Chemical insecticides are used in winter to control the mite, and the biological control, a predator mite from Chile, is introduced when tomato plants are growing.

20.5 MAN AND RESOURCES

The Earth's *natural resources* include the *physical* resources of water, air, soil, chemical elements and fossil fuels, together with all other species of living organisms.

(a) Living organism resources

Man's activity in *overhunting* and *overfishing* have resulted in some cases in the *extinction* of a species never to reappear on Earth again. Extinct species include the dodo, great auk, giant moa, New Zealand flightless goose, Carolina parakeet, pinhead duck and passenger pigeon.

A great number of species are now classed as *endangered* species liable to extinction unless preserved or maintained. The baleen whale is an endangered species reduced to between 6 and 8% of its original numbers through overkilling.

Many countries depend on food from the sea; this has led to overfishing of productive *coastal* waters, leading to the finding of new deep-water fishing grounds and even new species of fish for food.

Deafforestation and cutting down of natural woodlands for land clearance and building material, together with removal of hedges, destroys natural habitats of organisms.

(b) Land resources

Only 30% of the Earth is land, the remainder being water. Man is a *terrestial* animal and his increasing population makes more *use* of the land, depriving other organisms.

The following is a summary of the usage of the 24 M hectares of land in the United Kingdom: farmland, 50%; mountains and moorlands, 30%; towns and cities, 10%; roads, airports, railways, 7%; water, rivers and lakes, 3%.

Every human requires one hectare of land for an adequate diet. In the United Kingdom there is only 0.4 hectares per person, and consequently the United Kingdom produces 75% of its food needs and imports 50%. In addition, 25% of the food in the United Kingdom is wasted, either by action of *pests* consuming food in stores, or that it is surplus to our needs. Only Canada and the USA are able to *produce* a surplus of food.

The increasing population requires *more* farmland for homes, industry, recreation, and roads, and *more* food to feed them.

(c) Water

Water, food, timber and natural materials for clothing are *replaceable* resources. Water is recycled by processes in the ecosystem.

Man's *use* of the resources of water affect the *natural* recycling process. Water reserves are kept in lakes, reservoirs and wells; these are used in great amounts by power stations and manufacturing industry. The *used* water is then rapidly returned to the sea by *drains*, or through *land* drainage.

Water is used so rapidly from the *reserves* that it is not replaced fast enough by rainfall. Water purification and sewage treatment are comparatively *slow* processes compared to the rapid water usage processes for cooling purposes in power stations.

(d) Fossil fuels

Coal, oil, peat and natural gas are *non-replaceable* resources; once used, they provide energy, which flows to outer space, and carbon dioxide together with water vapour in the air.

Present stocks of fossil fuels in the United Kingdom are being used up at a rate that will last until the year 2100.

Fossil fuels, apart from being sources of energy, are also important and *sole* sources of raw materials for producing *chemical compounds* for making medicines, fertilisers, plastics, man-made fibres, dyes, pesticides, detergents, explosives, perfumes and synthetic flavours.

(e) Chemical elements

Chemical elements are circulated in the *natural* ecosystem by carbon, nitrogen and oxygen cycles. Agricultural fertilisers are obtained by mining, mineral deposits, whilst manufacturing industries use mineral ores from various non-replaceable sources to produce different metals and chemical compounds.

The world has a *finite* or limited supply of chemical elements in *known* reserves; in addition there are unexploited sources on the seabed and also undiscovered mineral sources. The present *known* reserves of different metals are expected to last as follows based on present consumption rates: lead, 24 years; copper, 34 years; zinc, 17 years; tin, 15 years; nickel, 49 years. After this time, new deposits must be discovered or seabed and low-grade ore sources exploited.

20.6 MAN AND POLLUTION

Pollution is a process of adding excess or waste substances and energy from industrial, agricultural and other activities of an increasing population of human beings.

Pollutants include noise, heat and radiation as different forms of *energy*, together with many *chemical* elements or compounds, and *excretory* products. These pollute the air (Plate 20.3), water or land, causing *ecological* effects and *physiological* effects on living organisms.

plate 20.3 *motor vehicle exhaust gases and air pollution (World Health Organisation)*

(a) Air pollution

Table 20.5 summarises the main pollutants in air together with their sources, effects on living organisms and methods of control.

(b) Water pollution

Foul sewage contains human waste excretory products that can be disposed of by the following methods:

Burial in earth pits or distribution on the land to improve the soil fertility as in parts of Asia.

Dilution with water and discharge untreated into the sea for further dilution. This method is employed in many coastal villages in the United Kingdom and in Mediterranean countries.

Biological treatment for foul sewage and *storm* water produced by rainfall. The *sewage* is treated by *screening* to remove sticks and rags, *sedimentation* to allow silt and *sludge* to separate. The liquid from sedimentation tanks is treated *biologically* by algae, aerobic bacteria, protozoa and fungi acting as *decomposers.* Bacteriophage viruses also attack harmful bacteria. The comparatively clean water is discharged into rivers or estuaries.

Sludge can be used to generate methane gas as a fuel by activity of anaerobic bacteria, and dried for fertiliser use.

(i) *Oxygen-reducing pollutants*

The natural oxygen content of water is vital for aquatic organisms and can be reduced by *hot* water from power station coolers reducing oxygen gas solubility, *sewage*, *detergents* and *sulphite* (from wood pulp factories). These pollutants can affect aquatic food chains, and faecal pollutants cause intestinal disorders in man.

Soap and certain soft soapless detergents are *biodegradable* and consumed by microbes; other *hard* soapless detergents are not biodegradable and cause 'foaming' in sewage effluent.

(ii) *Poisons*

The natural weathering of rocks and mineral ore deposits causes a *natural* increase of lead and mercury in sea water. Manufacturing and chemical industries discharge metal salts of lead, mercury, nickel, chromium and arsenic in factory effluents.

Lead and mercury accumulate in animal tissue, and increasing amounts are found in fish.

Disinfectants containing phenols are also sources of water pollution.

(iii) *Eutrophication*

This is a *natural* process by which large amounts of living organic material form in water well supplied with soluble nutrients. Lakes slowly develop large concentrations of aquatic plant life, which eventually decays.

Human activities have *speeded* up this natural process of eutrophication

Table 20.5 *air pollution*

Pollutant	*Sources*	*Effects on living organisms*	*Control measures*
Carbon monoxide, CO	1 80% motor vehicle exhausts 2 Incomplete combustion of fossil fuels 3 Tobacco smoking	1 Prevents oxygen usage by blood – forms carboxy-haemoglobin 2 Death in a closed garage 3 Persists for several years	1 Vehicle exhaust gas control in USA; none in UK* 2 Efficient combustion of fossil fuels in industry and home 3 No smoking
Sulphur dioxide, SO_2	Combustion of sulphur-containing fuels, oil, coal gas, coal and smokeless fuels. 80% from industry and power stations. NB: natural gas does *not* form SO_2	1 Bronchitis and lung diseases. Many deaths in UK 1952 smog 2 Rapidly changed into ammonium sulphate and sulphuric acid 3 Affects photosynthesis	1 Use of sulphur-free fuel – natural gas 2 SO_2 extraction units in industrial flues and chimneys
Ozone, O_3	Motor vehicle exhausts	1 Eye irritation, headaches, nasal irritation. Aggravates lung bronchitis 2 Causes internal damage in leaves	Vehicle exhaust gas control*
Smoke and tarry hydrocarbons	1 House coal smoke soot 2 Smoking lorry exhausts 65% hydrocarbons 3 Tobacco smoke tars	1 Lung cancer and other lung disease 2 Smog (see below) 3 Rickets – Vitamin D deficiency 4 Sunlight barrier 5 Stunted growth of plants 6 Stomatal blockage	1 Smokeless fuels 2 Efficient combustion 3 No smoking 4 Motor vehicle exhaust controls*
Dust and grit	1 Solid fuel ash 2 Soil 3 Industry – mines, cement, quarries 4 Motor vehicles – rubber, asbestos	1 Lung disease – silicosis, asbestosis 2 Smog by temperature inversion 3 Stomatal blockage 4 Stunted growth of plants	1 Dust precipitators in industrial chimneys 2 Efficient combustion 3 Face masks worn by garage and factory workers

Carbon dioxide increasing from 0.03% to reach 0.04% by volume. 12% increase in last 100 yr	1 Combustion of fossil fuels 2 Motor vehicles	1 None, except in poorly ventilated spaces. Headache, tiredness 2 'Greenhouse effect' – warming up of Earth's atmosphere? 3 Used in photosynthesis	1 More green plants 2 Plant more trees 3 Less combustion of fossil fuels
Lead	Petrol antiknock or tetraethyl lead	1 Collects in bone 2 Causes nervous disorders 3 Absorbed by roadside plants	Remove or reduce tetraethyl lead in petrol. Use low compression engine
Nitrogen oxides	1 Car exhaust gases 55% 2 Industrial flue gases 45%	1 Harmful as nitrates in water fed to young babies 2 Cause of 'photochemical' smog	Exhaust control as for USA*
Chlorofluorohydrocarbons	Aerosols	1 Skin cancer from UV light 2 Heart and lung disorders? 3 Enters stratosphere, reducing ozone layer and permitting greater penetration of UV light	Banned in Oregon, USA – use mechanical sprays as alternative
Noise	1 Discos 2 Road traffic 3 Engines 4 Machines – road drills 5 Aeroplanes – jets 6 Firearms	1 Hearing impairment 2 Total deafness 3 Nervous disorders	1 Noise abatement 2 Insulation 3 Ear muffs and plugs in industry

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*Exhaust gas control systems produce small amounts of hydrocarbons (unburnt fuel), carbon monoxide, ozone and nitrogen oxides in the exhaust gases by using special carburettors in the engines. These are used in USA and Canada *only*. Petrol evaporation into the air from petrol tanks of cars is also controlled in North America.

by adding mineral and organic nutrients in larger quantities than Nature would provide, as excreta, phosphates from washing powders, and fertilisers which *leach* from heavily fertilised land as nitrates and phosphates.

Vast quantities of *algae* feed and reproduce on these nutrients causing the water to turn green with an *algal bloom*. The dead algae are decomposed by *aerobic* bacteria which deplete the water oxygen content causing death of aquatic animals through oxygen lack.

(iv) *Hydrocarbon oils*

Shipping is responsible for 40% of oil pollution, whilst industry and motorists pollute water with waste engine oil by disposing of it in the drains. A film of oil on water reduces oxygenation, and tarry oils foul marine animal life. It is believed that oil is naturally dispersed in oceans, whilst the use of detergents to disperse oil creates another problem.

(v) *Pesticides*

Pesticides and herbicides accumulate in water by leaching of water off agricultural land, or by spray drift. Their effects and concentration in food chains are described in Section 20.4

(c) Soil and land pollution

Lead and cadmium from mine tips and pesticides collect in soils to be leached into rivers and oceans as described earlier. Food chains of organisms of the soil habitat are also affected, upsetting the ecosystem balance.

Farm animal waste is dumped as a *slurry* on soil, whilst *domestic refuse* containing chemical waste can reduce soil fertility and poison the soil microbes. Exposed refuse becomes a breeding ground for houseflies and rodents.

Radioactivity: certain chemical elements are *radioactive*, disintegrating and producing alpha-, beta- and gamma-rays which can penetrate human tissues, the gamma-rays more so than the beta-rays (Section 5.13).

Rocks and soil provide a natural *background* radiation amounting to 70% of all harmful radiation received by living organisms. Hospital and laboratory equipment accounts for most of the remaining source.

Fallout from a nuclear bomb explosion can produce strontium-90 (^{90}S), a radioactive substance that enters the bodies of grazing animals, feeding on grasses in which it accumulates. Humans can *accumulate* the radioactive substance in bone tissue from milk, resulting in leukaemia.

20.7 MAN AND CONSERVATION

Conservation may be described as the means of restoring, maintaining and preserving ecosystems by a wiser use of natural resources.

(a) Conservation of processes in the ecosystem

Man by his industrial activities has interfered with *natural* cycling processes and consumed natural resources of chemical elements without recycling them.

(i) *Energy*

Solar energy *flows* through the ecosystem, less than 1% being used by living organisms (Section 18.9). More solar energy could be trapped by the *producers* to be converted into *alternative* energy sources as for example in *biofuels*; ethanol is produced in Brazil by anaerobic fermentation of plant carbohydrate. The ethanol is used as motor fuel.

Sun energy is increasingly used for *home heating*, which can be held in homes by improved *insulation*. Heat is absorbed by the ground and collects in water; this heat can be withdrawn by *heat pumps* for home heating.

Wind and water when they *move* can be used to generate electrical energy by windmills, waves, tides, rivers and waterfalls. Only 2% of United Kingdom power stations are *hydroelectric*.

Atomic or nuclear power produced in a nuclear reactor using uranium or plutonium fuels is only used in 12% of United Kingdom power stations.

Biofuels include the production of methane gas from animal faeces and sewage sludge. A cow produces 10 kg of dung daily, capable of producing 0.35 m^3 of methane, sufficient to heat one room for 12 h.

Living human bodies release body energy which could be used to greater effect where large numbers of people meet in schools, etc.

(ii) *Chemical elements*

Man moves chemical elements and minerals *into* ecosystems from concentrated natural deposits for use as inorganic *fertilisers*, or *metal* sources from mineral ores, or for manufacture of chemical compounds.

Many of these chemical elements *leave* the ecosystem by being *leached* from the land and drained into the rivers to accumulate in oceans. Other chemical elements after use as metals in cars and cans are *scattered* over the Earth's surface.

Fertilisers which do *not* leach from agricultural land need to be developed and 'locked in' to soils.

Nitrogen-fixing bacteria need to be encouraged in order to replace expensive consumption of *nitrate* deposits, mined, transported and distributed by expensive *energy* from fossil fuels.

(1) Recycling

Recycling of materials and metals needs to be more widespread. Sterile sewage *sludge* can be used as an animal protein feed supplement. Farmyard manure *slurry* can also be used to rear earthworms or fly maggots, which are 70% protein, to feed poultry, pigs and calves.

Paper can be recycled with comparatively *less* energy than is used in its production from wood pulp.

Glass recycling is a process using *less* energy than glass manufacture.

Motor vehicles consume fossil fuel and this should be replaced by a *biofuel*, ethanol. Engine lubrication oil could be recycled after collection at oil recovery centres.

Metals used in motor vehicles are recovered at present on the following percentage recovery basis: iron and steel, 90%; lead 100%; aluminium, copper and zinc, less than 1% recovered.

Of the *total* consumption of metals in the United Kingdom, the following percentages are recovered from *scrap*; lead, 30%; aluminium 38%; copper, 20%; zinc, 2.5%; and tin, 39%. This indicates that a greater effort could be made in the collection and recycling of scrap metals.

(b) Conservation of plant and animal life

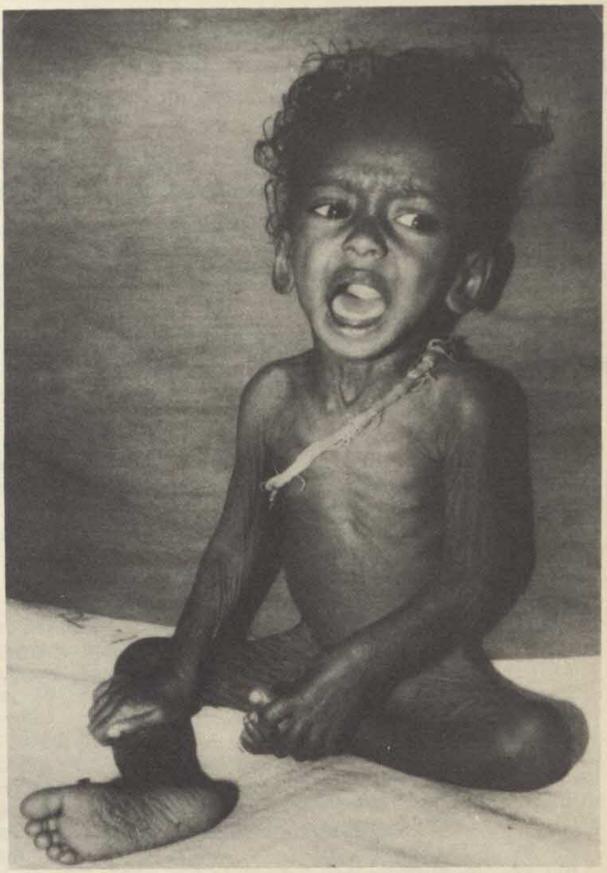
Species in danger of extinction must be preserved in preservation *areas*: nature reserves, wildlife parks, national parks, zoos and botanical gardens; through the preservation *bodies*: World Wildlife Fund, Department of the Environment, National Environment Research Council, Countryside Commission, Nature Conservancy Council and the Ministry of Agriculture, Fisheries and Food. *Laws* have been enforced to protect and preserve, such as the following: Protection of Birds Act, Conservation of Wild Creatures and Wild Plants, Conservation of Seals, Tree Preservation Orders, National Parks and Access to Countryside Act; and *bye-laws* such as: the Game Laws, Protection of Wild Flowers.

Food sources must increase to *three* times the present level of production if *everyone* in the next 20 years is to have an adequate diet. At present 60% of the world population suffers malnutrition and between 10 and 15% are *hungry*, and 0.25% (mainly children) are *near starvation* (Plate 20.4).

In the United Kingdom 25% of our food is *wasted*, whilst 50% of the food which is in store in tropical countries is consumed by *pests*.

Food technology can provide alternative food sources from yeasts and soya bean, in the form of textured vegetable protein. *Fish farming* can improve production of food from the sea. *Land reclamation* for agriculture from spoil heaps and industrial sites can be supplemented with *marginal* land reclamation on moorlands and uplands.

plate 20.4 *a child of 13 months weighing 3.94 kg, suffering from* marasmus *arising from extreme starvation (World Health Organisation)*



20.8 QUESTIONS

1 By reference to the following, describe how man's activities have affected living organisms in the environment: (a) bacteria; (b) fish; (c) plants; (d) mammals; (e) insects.

2 Explain what are meant by animal and plant monocultures?

3 Describe the biological significance of: (a) the use of organic manures; (b) liming: (c) crop rotation. How are the organic content and pH of a soil determined experimentally?

4 By reference to the following, describe how man's activities have affected the non-living components of the environment: (a) fresh water; (b) sea water; (c) air; (d) mineral resources.

5 Write brief notes on each of the following: (a) recycling; (b) biological control; (c) eutrophication; (d) non-biodegradable materials; (e) fossil fuels.

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